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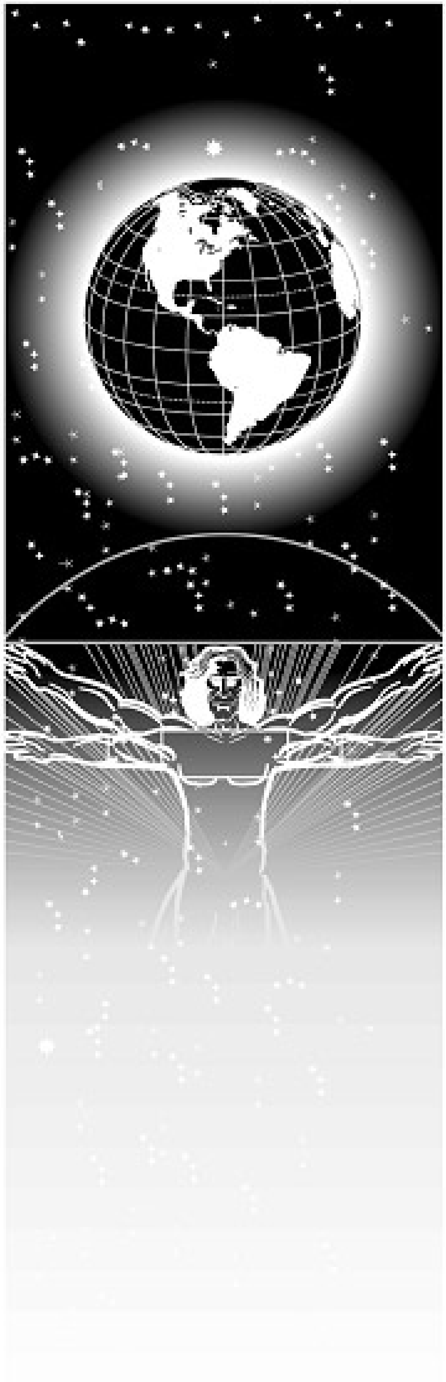

UNITED STATES AIR FORCE RESEARCH LABORATORY

IMPACT OF PRIOR FLIGHT EXPERIENCE ON LEARNING PREDATOR UAV OPERATOR SKILLS

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Unmanned/uninhabited aerial vehicles (UAVs) are an increasingly important part of military operations throughout the world. However there is no consensus about who should fly these aircraft. A United States Air Force (USAF) Corona South four-star general officer summit in 1997 resulted in tasking the Air Force Research Laboratory to conduct a study to compare the speed and accuracy with which various groups of pilots could learn to fly the RQ-1A Predator UAV. This study primarily addressed stick-and-rudder skills; we did not measure such operationally relevant factors as communication skills, command experience, and knowledge of combat operations. Seven groups of military and civilian pilots, varying in amount and kind of flying experience, completed a series of multimedia tutorials on principles of flight and procedures for operating the Predator, then flew a high-fidelity RQ-1A simulator. Each participant flew basic maneuvers and landings (including difficult crosswind landings) until a very high standard of aircraft control performance was achieved, then flew 30 reconnaissance scenarios. During this time, detailed measures of performance were continuously and automatically recorded. The results show that, though Predator pilots performed best (and nonpilots performed worst), Air Force T-38 graduates and civilian pilots with single-engine instrument training performed nearly as well as a group of highly experienced military pilots assigned (but not yet trained) to fly Predator. A possible explanation for the relatively good performance of the T-38 and civilian instrument pilots is that there may be advantages to recent experience flying aircraft that have handling characteristics that are similar to the Predator.

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CONTENTS

PREFACE

This research was conducted for the Air Force Research Laboratory (AFRL) under Work Unit 2313-HA-05, Uninhabited Aerial Vehicle Training Research. The Air Force Office of Scientific Research (AFOSR) provided initial funding. The AFOSR Program Officer was Dr. John Tangney (AFOSR/NL). Air Combat Command (ACC) provided funding for expansion of the study and development of the high-fidelity simulation. The ACC Program Officer was Col. Harold Barton (ACC/DOU). The effort was supported by Link Simulation and Training Division of L3 Communications and Lockheed Martin under Task Order 10 of Contract F41624-97-D-5000, Warfighter Training Research Support. Principal Investigator for AFRL's Warfighter Training Research Division was Dr. Elizabeth L. Martin. Laboratory Contract Monitor was Mr. Jay Carroll.

We wish to thank the 11th and 15th Reconnaissance Squadrons at Indian Springs Air Force Auxiliary Field (AFAF) for their continued cooperation and support over the past four and a half years. We also thank the members of the 14th Operations Group at Columbus AFB, MS and the faculty and the Reserve Officer Training Candidate (ROTC) detachment at Embry-Riddle Aeronautical University (ERAU) in Prescott, AZ for their dedicated support of this study. In addition, we wish to thank all the participants who volunteered for the study and the following individuals (listed alphabetically) who each contributed generously of their talent and time:

Maj. Jon Box (Ret.), Predator subject-matter expert and study co-experimenter, TASC.
Mr. Sean Jeralds, Director of Flight Training, ERAU.
Mr. Guy Parker, President, Parker International, developer of the Predator simulation.
Mr. Eric Watz, contractor Software Engineer, AFRL/HEA.
Mr. Carey Ziter, Predator subject-matter expert.

Finally, we wish to extend special thanks to Mr. Stan Baker, Autometrics at ACC/DOR, for his support, guidance, and tireless effort on our behalf.

EXECUTIVE SUMMARY

UAVs (Unmanned/uninhabited aerial vehicles) are an increasingly important part of military operations throughout the world. However there is no consensus about who should fly these aircraft. The United States Air Force (USAF) uses experienced pilots who have already had at least one operational tour of duty in another combat aircraft. By contrast, the U. S. Army's Hunter UAV is flown by enlisted personnel (generally non-pilots) who are given a UAV-specific training program. Other possibilities include students at various stages of military pilot training, or civilian pilots under contract to the military. A USAF Corona South four-star general officer summit in 1997 resulted in tasking the Air Force Research Laboratory (AFRL) to conduct a study to compare the speed and accuracy with which various groups of pilots could learn to fly the RQ-1A Predator UAV. This report contains the procedures and results of that study.

For this study we used a high-fidelity RQ-1A simulator developed in cooperation with experienced Predator pilots at Indian Springs Air Force Auxiliary Field (AFAF). Seven groups of pilots, varying in amount and kind of flying experience, completed a series of multimedia tutorials on basic principles of flight and procedures for operating the Predator, then flew the simulator. These groups were: (a) experienced USAF Predator pilots; (b) experienced USAF pilots recently selected to fly the Predator; (c) students recently completing USAF T-38 training; (d) students recently completing USAF T-1 training; (e) students recently completing single-engine instrument training at Embry-Riddle Aeronautical University (ERAU); (f) students recently completing requirements for a private pilot's license; and (g) Reserve Officer Training Candidate (ROTC) students at ERAU who intend to be USAF pilots but who had no flying training or experience. Each participant flew basic maneuvers and landings (including difficult crosswind landings) until a very high standard of aircraft control performance was achieved, then flew 30 reconnaissance scenarios. All of this required between 12 and 30 hours, depending predominately on the skill of the participant. During this time, detailed measures of performance were continuously and automatically recorded.

The results show that experienced Predator operators performed consistently better than other groups, while the nonpilot ROTC students performed worse. This is not surprising, but it confirms that the simulation used in the study was a valid indicator of Predator stick-and-rudder skill. A more surprising finding is that, from a pure aircraft control perspective, T-38 graduates and civilian instrument pilots performed nearly as well as the much more experienced pilots currently selected for Predator training. A possible explanation for relatively good performance of the T-38 and civilian instrument pilots is that there may be some advantages to recent experience flying aircraft that have handling characteristics that are similar to the Predator in some ways.

This study applies only to the Predator, and primarily addresses stick-and-rudder skills; we did not measure such operationally relevant factors as communication skills, command experience, knowledge of combat operations, or familiarity with airspace management, especially in war zones. Since such knowledge and skills are necessary for a Predator pilot, the current USAF policy of using pilots who have had prior operational tours should only be altered if it can be assured that less experienced pilots can achieve this critical competence in some other way.

INTRODUCTION

The role of unmanned/uninhabited aerial vehicles (UAVs) is expanding rapidly in military operations after a period of dormancy. UAVs are becoming a mainstay of intelligence, surveillance, and reconnaissance (ISR) information gathering, with the capability of supplying, in near real-time, visual information to theater command and control centers and to pilots in their cockpits. The number and type of UAVs is also expanding. UAVs may become increasingly involved in more direct combat roles involving weapons deliveries for various air combat missions. Already, the United States Air Force (USAF) Predator (officially designated RQ-1) has been used to deliver Hellfire missiles and to laser-designate targets. The USAF has the Unmanned Combat Air Vehicle (UCAV) in development. The UCAV has had a weapons delivery capability from its original conception. The Global Hawk, a high-altitude ISR aircraft, is nearing an initial operational capability (IOC) date. The other services have a variety of other UAVs in service and many are on the drawing board for the future. In 1996, the USAF Scientific Advisory Board identified 22 different missions that could conceivably be adequately performed by UAVs. How many of these will be fulfilled remains to be seen; but it is clear that UAVs will become increasing more important.

Who should operate and employ these aircraft? Military personnel? Officers or enlisted? Pilots? DoD civilians, contractors? The issue of selecting and training operators has been a topic of discussion among senior military leadership. What types of skills are required? What kind and how much training are required? Should there be a specialized UAV career field? Implications of the answers to these types of personnel staffing questions have both short-term and long-term implications. Currently, across different military services, there are vast differences in both the types of personnel who are selected to become UAV operators (Weeks, 2000) and the training programs.

While opinions are varied and easy to come by (Tobin, 1999), there is very little empirical research to guide the leadership in determining the best policy for selection and training. As a direct result of the 1997 Corona South four-star general officer summit, the Air Force Research Laboratory (AFRL) undertook a study to determine the skills required to operate the Predator UAV--the only operational UAV in the USAF inventory (Hall & Tirre, 1998). The initial study was a survey of experienced Predator pilots. This study concluded that some manned flying experience was necessary for pilots to be successful and that this experience should be roughly comparable to undergraduate pilot training (UPT). However, the conclusions of that study were based on opinions. There was a desire to follow up the opinion survey with a study that contained some performance measurement data addressing the issue. The study presented in this paper is the result. The purpose of this experiment was to determine how much, if any, flying experience is necessary to successfully operate the Predator UAV.

Because there are a number of potential issues that can be raised in this context, it is important to state what the intent of this study was not, as well as what it was:

- It was not the purpose to address the issue of officer vs. enlisted. It was stipulated at the outset that as a matter of policy the USAF was not considering the use of enlisted personnel.

- It was also not the intent to include many skills that may fall under the rubric of "airmanship" resulting from command experience (e.g., communication up and down the chain of command, tactical decision making). The comprehensive set of skills required is far too large to be adequately addressed in one experiment.

- It was not the intent to conduct a study pertinent to all UAVs. The present study was limited to the Predator and the results are intended for application to the Predator system only. Other UAVs may be highly automated with far different missions and concept of operations than Predator. It should be noted that several significant changes to the Predator (both system and mission) have occurred since this study was initiated.

- It was not the intent to address issues such as creation of specialized UAV career fields, training syllabus, tour length, or follow-on assignments. For example, if new graduates of T-38 training were selected to fly the Predator, would their flying skills be maintained sufficiently to receive a subsequent assignment to a fighter aircraft? Issues such as this require a different study methodology.

- This study did not attempt to identify the role that motivational factors play in performance on the experimental tasks.

- The Predator is crewed by a team of operators. This experiment did not address any "team" issues.

- Some changes from the original research plan were required due to logistics and funding constraints. The original plan included testing of nonpilots at the Air Force Academy (we used Air Force Reserve Officer Candidate [ROTC] students instead). It also included a group of students who were planning to enter Air Force career fields other than flying; and it included some pencil-and-paper ability testing of some of the groups. In our view, none of these changes affected the validity of the study.

It is a fair characterization to say that this experiment focused on the psychomotor and perceptual skills required to pilot the Predator. It is possible that the results of the study may be used to guide decisions regarding some of the issues mentioned above, but it would have to be done in combination with other data, information, and assumptions.

Currently, the Predator pilot is a military pilot with experience in at least one other operational weapons system. Due, in part, to a critical shortage of military pilots available for manned aircraft, the question arose as to whether the pilot position for the Predator needed to have such extensive qualifications. In fact, on occasion, an experienced weapons system operator or navigator with a commercial instrument rating has been selected for Predator pilot training. While it is certainly the case that the pilot shortage is a short-term situation, the issue is valid in any case. The expected expansion of the numbers of UAVs requires that these very issues be answered sooner rather than later. What are the most logical alternatives?

Based on the results of the initial survey, the most likely candidate groups seemed to be UPT graduates or officers with commercial instrument pilot credentials. However, it is always wise to bound an experiment with top, bottom, and intermediate levels of the critical variable, in this case, flying experience. So, a group of individuals who meet the physical and intellectual requirements but had no flying experience would constitute the bottom of the experience dimension. In this case, this level was filled with Air Force ROTC cadets who had no previous flying experience. The top level of experience was filled by current mission-qualified Predator pilots.

Given time and resources, most people who meet the physical and intellectual requirements of an Air Force officer could be trained to operate any system. However, the current initial qualification train-

ing (IQT) for the Predator leverages heavily from an assumed entry level of knowledge and experience in the operational military aviation system. Any change from the current selection policy will undoubtedly have ramifications for the design of the training program. Therefore, it was also the intent of this study to design the experiment so that it has relevance to the training issues as well as selection issues.

OBJECTIVE

The objective of this study is to provide empirical evidence on the question of how quickly and how well Predator piloting skills can be learned by various groups of pilots (and future pilots) who differ in amount and type of prior flight training and experience. The study addresses the set of skills required to control a Predator accurately during difficult maneuvers. It also provides some data regarding the skills required to stay oriented while maneuvering to accomplish a specific reconnaissance objective. However it was not designed to address other skills that are important components of a well-rounded operator, for example, combat airspace management, communicating information to a command chain, and other officership issues.

APPROACH

Participants

Participants were recruited from several groups of pilots (or students wishing to become pilots). Five of these groups represented populations from which future Predator UAV pilots could conceivably be drawn (i.e., candidate groups); two others were reference groups at the extreme ends of the flying experience spectrum.

Experienced Predator Pilots. Six experienced pilots participated at their operational location, Indian Springs Air Force Auxiliary Field (AFAF), NV. Their ages ranged from 29-43 years; all were men with the rank of captain. Flying experience ranged from 1,680 to 2,942 hours, of which between 80 and 340 were Predator hours. All had at least one tour of duty in another operational aircraft. Five came from wide body tanker, transport, bomber (TTB) aircraft assignments; one came from fighters.

Predator Selectees. Twenty-four Predator selectees were scheduled for data collection during their first week assigned to Indian Springs AFAF, before any Predator training had begun. Data from two selectees were not used because it was incomplete due to scheduling or other logistics problems. Navigators with commercial instrument ratings are currently part of the Air Force selection pool for Predator UAV pilot duty, but were not originally a planned group in our study. Since this population was available at Indian Springs during the study, we included navigator selectees in hopes of obtaining a navigator group large enough to compare with other groups. However, only four navigators were obtained--an insufficient number to include as a separate group in the study.

The remaining 18 pilots, 17 men and 1 woman, formed the Selectee group used here. Their ages ranged from 26-43 years. The distribution of ranks was: 1 lieutenant, 14 captains, 1 major, 1 lieutenant colonel-select, and 1 lieutenant colonel. Flight experience ranged from 417 to 3,010 hours. All had at least one tour of duty in an operational aircraft. Ten came from TTB aircraft assignments; eight came from fighters.

T-38 Graduates. Eighteen T-38 students were tested at their training site (Columbus Air Force Base, MS) after successful completion of all training, just before official graduation ceremonies. Data from three of these were not used because it was incomplete. The remaining 13 men and 2 women ranged in age from 23-29 years; 13 were lieutenants, two were captains. Students completing the T-37/T-38 UPT program finish with 195-215 total hours.

T-1 Graduates. Nineteen T-1 students were tested at their training site (Columbus Air Force Base, MS) after successful completion of all training, just before official graduation ceremonies. Data from three of these were not used because it was incomplete. The remaining 14 men and 2 women ranged in age from 23-28 years; 14 were lieutenants, two were captains. Students completing the T-37/T-1 UPT program finish with 195-215 total hours.

Civilian Instrument Pilots. Sixteen students who recently completed requirements for the civilian single-engine instrument (Course FA251) were tested at their training site (ERAU, Prescott, AZ). Data from one of these were not used because it was incomplete. The remaining 15 pilots ranged in age from 20-31 years; all were men. Flight experience ranged from 120 to 177 hours, typically in Cessna (172) and Beechcraft (Be 76) aircraft.

Civilian Private Pilots. Seventeen students who recently completed requirements for the civilian private pilot license were tested at their training site (ERAU or Williams Gateway Airport, Mesa, AZ). Data from four of these were not used because it was incomplete. The remaining 13 pilots (10 from ERAU, 3 from Williams) ranged in age from 18-25 years; all were men. Flight experience ranged from 45 to 80 hours, typically in a Cessna 172 aircraft.

ROTC Students (nonpilots). Sixteen Air Force ROTC students were tested at ERAU. They ranged in age from 19-22 years; all were men. None had any flight experience, but all intended to go into Air Force pilot training.

Participant Compensation. The Predator pilots, Predator selectees, T-38 graduates, and T-1 graduates all participated in this study as part of their normal Air Force duty day. Participants from the three civilian groups—instrument pilots, private pilots, and ROTC students—were paid $15 an hour for their participation. It is important to bear in mind that these differences in the way the participants were compensated, together with other potential sources of motivational differences between groups, could have affected observed group differences, although there were no obvious indicators of such effects in the data.

Although the participant groups differ in flying training, experience, and other factors, they share two important characteristics: (a) almost all participants either have a bachelors (or higher) degree, or are currently enrolled in a program to obtain one; and (b) all of them share a strong interest in a career as a pilot.

Study Procedures

As an extension to an ongoing research project, Air Combat Command (ACC) requested AFRL's Warfighter Training Research Division (AFRL/HEA) to develop RQ-1A Predator simulators for the 11th and 15th Reconnaissance Squadrons. Several training simulation systems were developed for AFRL by Parker International and the ACC Training System Center (TSC) Squadron Detachment 1 at Luke AFB

Figure 1. Predator UAV simulation.

AZ and are currently in use by operational Predator pilots at Indian Springs AFAF, NV. Just before data collection commenced, RQ-1A system #4 was the most current, so that simulation environment was the basis for the tasks given to all participants in the current study (Figure 1). The simulation environment was modified to allow the measurement of participants' performance while flying three tasks—Basic Maneuvering, Landing, and Reconnaissance. The simulation was run on a dual-Pentium PC, with an additional PC networked to it for experimental control and presentation of tutorial materials. Participants controlled the simulated Predator with the same primary controls used on the actual system--stick, throttle and rudder pedals (Note: though System #4 did have a control for propeller pitch, the plane did not have an adjustable propeller, so we did not provide the control. We also did not provide the flap lever control device, because Predator pilots stated they would not adjust the flaps during any of our three tasks, either in simulation or with the actual plane).

Figure 2 shows the equipment used for the study. Tasks were presented on two side-by-side 19" color monitors, the left displaying the exact System 4 "Heads-Up Display (HUD)" instrumentation overlaid on either a pure black screen (Basic Maneuvering Task) or a computer-generated camera view (Landing and Reconnaissance Tasks), and the right monitor displaying the tracker map display and associated symbology. A panel on the right of the tracker map presented additional information relevant to the task. Some of this information would normally be available from the variable information tables (VIT) in the actual Predator ground control station (GCS), while other information was pertinent only to our particular research tasks. A detailed description of each of the tasks used in the study, including pictures of the displays and description of the equipment, is given in Appendix A; software description is given in Appendix B.

The general sequence of events in the study was as follows:

After being briefed on the study purpose and signing consent forms, participants viewed a self-paced, computer-based tutorial that used text, graphs, pictures, overlays, videos, and animations to

Figure 2. Predator Synthetic Task Environment equipment setup.

convey declarative and procedural knowledge about the Predator simulation and the task to be flown. After finishing the Basic Maneuvering tutorial, the participant received a written test on the material. For incorrect answers, the participant was asked to review the tutorial to determine the correct answers. After assuring that the participant understood the tutorial material (i.e., a written test score of 100%), he or she was shown the displays and controls for the Basic Maneuvering Task, given written reference sheets for the task, and walked through a practice trial. Feedback was presented using graphical and text displays of performance measures. Then the participant repeated the Basic Maneuvering Task with computerized feedback until performance on all aspects of it reached criterion levels. The same general procedure was used for the other two tasks—first a computer-based tutorial, then a test, then a walk-through and practice trial, and then performance with feedback of the task itself. However, the Reconnaissance Task was run for a fixed number of trials (30, including practice) instead of running until criterion performance was reached. Following the reconnaissance trials, the participant filled out a demographic questionnaire and was debriefed. Total time required per participant was 12 to 30 hours, depending on how long a participant studied tutorial preparatory information and trial feedback graphs, and how many attempts were required to pass the Basic Maneuvering and Landing Tasks.

Research Tasks

Task Validity. Prior to the design of the research tasks, extensive structured interviews with experienced Predator operators were conducted at Indian Springs AFAF. These interviews were part of a cognitive task analysis designed to yield information about which parts of the Predator mission pose the greatest difficulties for the operators. Following this analysis, three tasks were designed to tap different aspects of Predator UAV piloting skill. The details of each task—breakdown of the task into elements or segments, design of scenarios, selection of performance measures, and setting of pass/fail criteria—were worked out with assistance from two former Predator UAV pilots under subcontract to AFRL/HEA. Fidelity of the handling characteristics of the underlying simulation was established through a long process of iterative testing by experienced pilots at Indian Springs AFAF.

Task Sequence. Since only the Predator pilot group was familiar with any aspects of the Predator UAV, the first task all participants encountered—the Basic Maneuvering Task—was designed

to bring all participants up to a common minimum proficiency level on stick-and-rudder skills operating the Predator UAV at altitude. Therefore, the Basic Maneuvering tutorial covered (a) basic declarative and procedural flight knowledge (for the benefit of the non-pilot ROTC group), (b) unusual UAV characteristics (e.g., control transmission delay, stability augmentation system), (c) other platform-specific information, such as the unusual HUD, and (d) instructional information specific to the Basic Maneuvering Task. Successful completion of the Basic Maneuvering tutorial and task demonstrated (a) memorization of gauge location and function, (b) familiarity with the aircraft handling characteristics and their interactions, and (c) ability to fly the Predator using instruments only. Finally, because successful completion of the Basic Maneuvering Task brought all participants to comparable competency levels on the above, differences observed in the following tasks (Landing and Reconnaissance, in that order) would be attributable to more complex skills, rather than basic learning of the instruments and general handling characteristics.

Basic Maneuvering Task. The Basic Maneuvering Task, similar to some civilian training tasks (e.g., standard rate turn) and derived from the task used in Wickens, Bellenkes and Kramer (1995), required participants to execute maneuvers in which the goal was to change one or more axis of flight--airspeed, altitude and/or heading--at a precise, constant rate of change during a 60-90 second trial. The criterion performance measure on each trial was deviation from the desired rate of change for each parameter, specifically the root-mean-square (RMS) deviation from the instructed rate of change for each of the three parameters. There were seven basic maneuvering subtasks (called “segments”). The first three segments required the participant to change just one parameter while keeping the other two parameters constant. The first was a constant-rate reduction in airspeed, the second was a constant-rate turn, and the third was a constant-rate change in altitude. The next three trials required changing two parameters simultaneously (for example, a constant rate turn while decreasing airspeed). The final segment required changing all three parameters. The participant flew each segment repeatedly until achieving RMS criterion simultaneously on all three parameters, and then was moved on to the next segment.

Landing Task. The Landing Task preserved much of the difficulty of landing a real Predator. Landing is considered the most difficult operational task Predator pilots face. The design characteristics of the UAV make it very responsive to control surface manipulations and sensitive to winds. Predator pilots cannot rely on vestibular cues during flare and touchdown (e.g., a sinking feeling), they have less optical flow information available, especially in the far periphery due to the small, 30-degree field-of-view camera (e.g., ground and bushes rising on the sides of the runway just before touchdown), and they must also deal with a line-of-sight control transmission delay.

The Landing Task used in this study incorporated all the above challenges and was designed to be the most difficult test of Predator stick-and-rudder skill. Successful completion of the Landing tutorial and task demonstrated that the participant was, to use piloting terminology, able to “fly several seconds ahead of the aircraft,” resulting in high levels of stick-and-rudder skill and an ability to predict how the plane would react several seconds after an action. (As a further experimental benefit, once this high level of stick-and-rudder skill was achieved on the Landing Task by all participants, any group differences observed on the subsequent Reconnaissance Task would be due largely to other skills beyond stick and rudder.)

At the beginning of a landing attempt, the participant is initialized on the downwind leg of an approach pattern commonly used at Indian Springs and must fly the rest of the pattern until touchdown

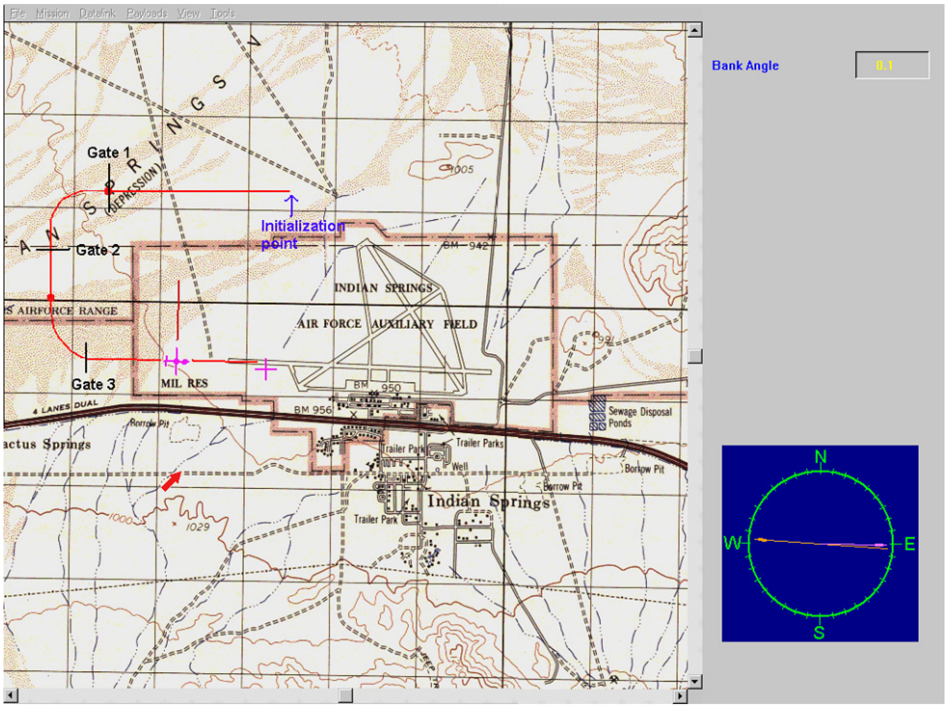

Figure 3. The tracker map is displayed on the right-hand monitor. This example shows a plane on final approach. The participant sees only the map and plane icon; we have superimposed the approach path (red line), turn points (red dots) and altitude gate positions (black lines) for illustrative purposes only.

(Figure 3). Landings without wind were flown repeatedly until criterion was reached simultaneously on thirteen criterion measures of performance (i.e., a perfect landing). These measures assessed error in approach altitude gates and groundtrack pattern, glideslope, and touchdown parameters (the complete list is in Appendix A.) Once a participant reached criterion on the no-wind landing, trials landing with crosswind were presented. (Interviews with experienced Predator pilots revealed crosswind landings as the most difficult part of any mission.) Before commencing with crosswinds, the participants viewed two instructional simulated Predator crosswind landing videos and were provided a crosswind declarative and procedural instruction sheet. Wind was always constant at 13 knots at all altitudes for all crosswind trials, but could originate from any of four directions--0 deg, 180 deg, 45 deg, or 135 deg for a given attempt. Participants were heading at approximately 90 deg on final. As with the no-wind trials, the participant flew repeated landings until a perfect landing was achieved, passing all 13 criteria simultaneously on a single landing attempt.

Reconnaissance Task. The third and final task involved the Predator's mission-- reconnaissance. On occasion, the Predator is tasked to obtain electro-optical imagery of a target under conditions of almost complete cloud cover. Under these conditions it is important to maximize the time during which an unobstructed view of the target is available so that all of the detailed reconnaissance objectives can be satisfied. Though this tasking is somewhat infrequent, it was the task deemed most difficult for the pilot on a Predator reconnaissance mission. A simulation task reflecting this mission is therefore the best opportunity to reveal performance differences between the groups in this study. The Reconnaissance Task requires the pilot to plan, maneuver in a target area, and maintain orientation (as opposed to the aircraft handling skill tested in the first two tasks). Initial interviews and task analysis indicated that difficult scenarios in this task would require substantial aviation-related spatial reasoning skills.

The Reconnaissance Task required the participant to fly 30 scenarios in which they were to obtain as much time-on-target as possible within a 10-minute scenario time limit. To perform each scenario, the participant must position the aircraft so that the sensor camera points toward a target through a small break in a cloud layer (Figure 4). Restrictions similar to those encountered in an operational mission are

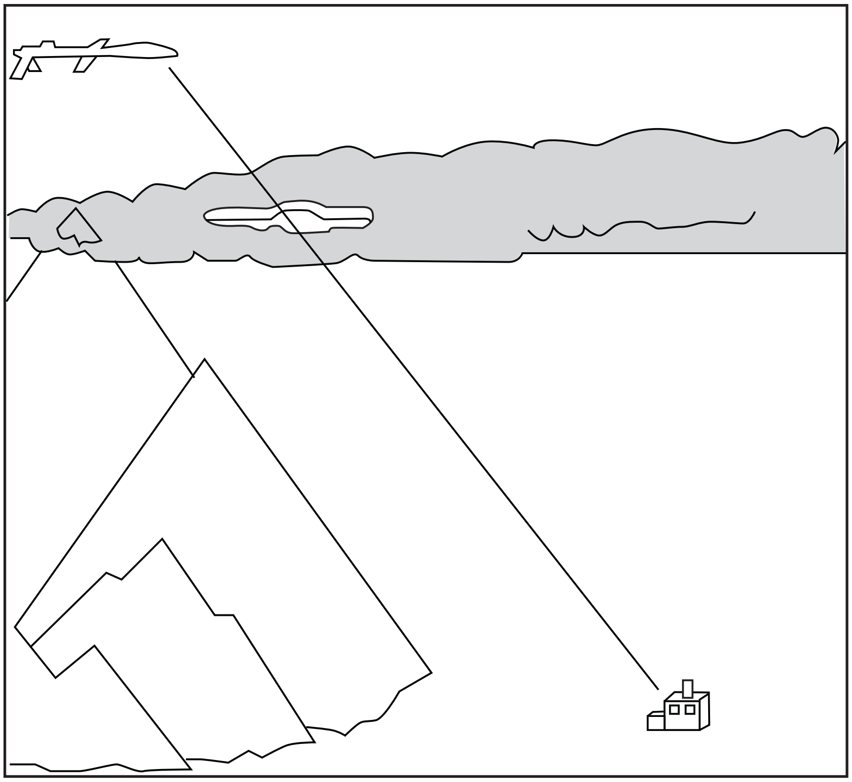

Figure 4. Schematic drawing of the Reconnaissance Task.

incorporated in the task. For example, participants are penalized for entering no-fly zones, violating altitude restrictions, stalling the aircraft, and exceeding bank and depression angle limits while viewing the target. Scenarios differed in wind direction (10-330 deg.), wind speed (0, 15, and 30 knots), and placement of no-fly zones near the area from which the target can be viewed.

To create our single-person pilot Reconnaissance Task, we always initialized the pilot in the immediate target area with targeting mode on (with the precise coordinates of the target), thereby focusing on the pilot-only skills involved in this type of reconnaissance mission (see Martin, Lyon, & Schreiber, 1998). At any time, the pilot could press a key to switch from nose camera view (to search for the cloud hole) to payload camera view (to accrue time on target). High time on target on the Reconnaissance Task demonstrates good planning, good understanding of the three-dimensional problem space, and proper execution.

Data Analysis

Each of the three synthetic tasks has a primary measure to best indicate successful performance. For the Basic Maneuvering and Landing Tasks, this measure is the number of trials required to reach criterion performance (i.e., successful completion). For the Reconnaissance Task, it is total time on target during a scenario. Each task also has numerous built-in subsidiary performance measures that provided further information about the nature of differences between groups.

Mean performance for each participant on each task was obtained for each measure. Group mean plots of selected measures (with error bars indicating plus-or-minus one standard error) are presented in the results section. Significance levels for the overall effect of pilot group were obtained using SPSS via a one-way analysis of variance (ANOVA). Given a significant overall effect, post-hoc tests for pairwise group comparisons (corrected for the number of comparisons within the ANOVA) were conducted.

In all three tasks, all trials after the initial walk-through trial were included in the analyses. However, in the Landing Task, the more detailed subsequent analyses excluded trials in which any of the following occurred in a given landing attempt: (a) the participant flew more than 50% of the way down the runway without landing; (b) the participant purposefully nosed the plane into the ground early in the trial to avoid having to complete an already spoiled landing; or (c) the participant pressed the abort key to indicate a "go-around" is necessary. Combined, these trials represented 2.8% of the total 7,124 landing trials examined.

For most analyses of the landing data, no-wind and crosswind trials were combined because a preliminary examination revealed no differential effect of the presence of wind on group performance. Wind simply increased the difficulty for all groups. However, for a few parameters, performance on no-wind trials was consistently better than criterion level for all groups, whereas potentially interesting differences between groups emerged only on trials with wind. For those parameters, wind and no-wind trials are graphed and analyzed separately.

RESULTS

The results of the study will be described as follows. First, the groups will be compared on the two primary overall measures, i.e.: (a) the combined total number of training trials required to achieve criterion performance through the crosswind landings (i.e., basic maneuvering attempts plus no-wind landing attempts plus crosswind landing attempts); and (b) total target data collection time during the Reconnaissance Task. Second, performance on each of the three tasks will be analyzed separately so that the determinants of overall performance can be understood. Finally, some of the data from the exit demographic questionnaire will be discussed.

Overall Performance

Total Basic Maneuvering and Landing Trials. Figure 5 shows the mean total number of training trials required to reach criterion on the combined Basic Maneuvering and Landing Tasks. This is the best estimate of the relative amount of practice required to bring groups up to a criterion Predator UAV stick-and-rudder proficiency level. The overall effect of pilot group was highly significant ($p < 0.001$). Predator pilots required the fewest training trials (50.2), whereas nonpilot ROTC students required the most (160.8)--more than three times the number required by pilots and significantly more than every other group except T-1 graduates. T-1 graduates required significantly more trials (123.7) than Predator selectees (84.6, $p = 0.039$) and civilian instrument pilots (84.5, $p = 0.047$). The other groups of pilots without Predator-specific experience (T-38 graduates and private pilots) did not differ significantly from each other or from either Predator selectees or T-1 graduates.

These results show that previous flying experience can substantially reduce the number of trials required to become proficient in basic maneuvering, and no-wind and crosswind landing. It should be noted that, for the Landing Task, the number of trials to criterion may be an underestimate of the true number of trials to reach criterion performance. Because the ROTC students were nonpilots, much learning needed to take place for them to complete the landings, especially crosswind landings. We determined that any participant who could not pass the landing trials within 200 attempts needed coaching to fully understand the complex stick-and-rudder skills necessary to land the Predator UAV in

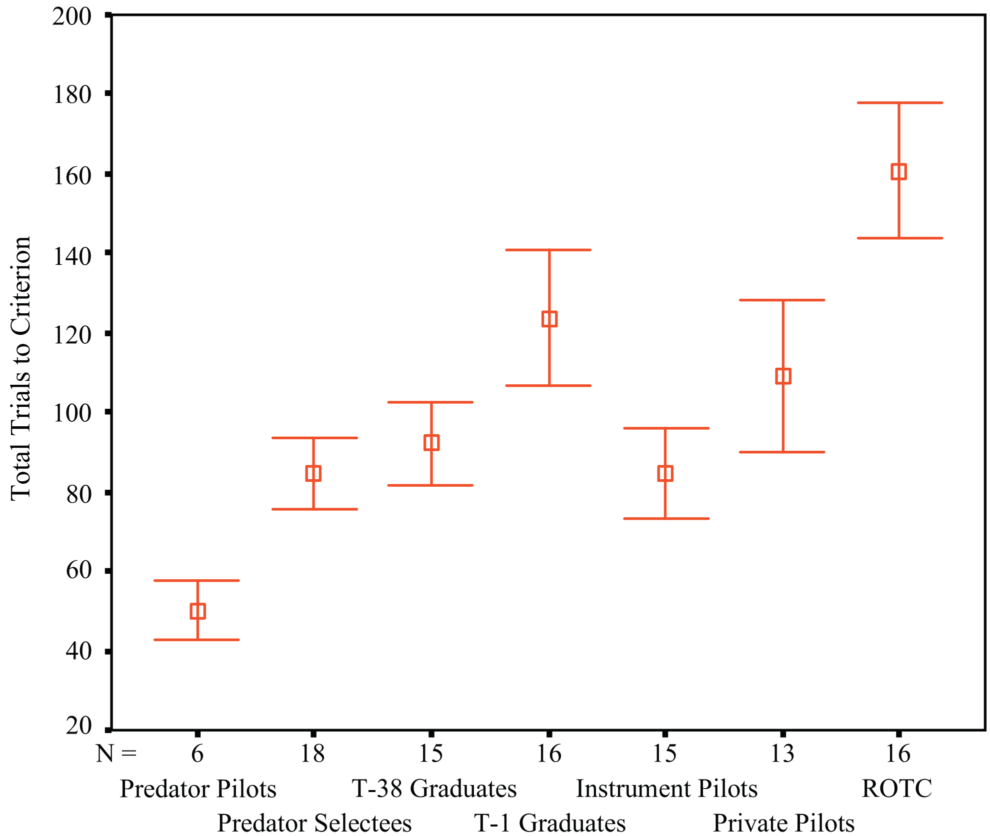

Figure 5. Total number of trials required to achieve criterion performance on Basic Maneuvering, No-Wind Landing and Crosswind Landing. Points are means of total number of trials for individuals within each group.

crosswind. While no pilot reached 200 attempts, three of the ROTC students reached this instructional intervention point. Without this intervention, those students might have required many more trials. Further, as the task-by-task analyses presented below will show, passing our strict criteria does not assure that pilots are equally skilled. So the differences between groups in number of trials should be viewed only in relative terms. The number of trials required to bring nonpilots to a skill level truly equal to Predator selectees on crosswind landings would probably require even more than the 76-trial difference observed here. Nevertheless, even this difference, if translated to landings with real aircraft, represents a considerable investment in training time and resources.

Reconnaissance Task Time on Target. Figure 6 shows the mean time on target during each scenario of the Reconnaissance Task. The effect of pilot group was highly significant ($p < 0.001$). Nonpilots logged significantly less time on target (90.2 sec) than Predator pilots (130.7 sec, $p < 0.001$), Predator selectees (125.2 sec, $p < 0.001$), T-38 graduates (126.0 sec, $p < 0.001$) and T-1 graduates (111.8 sec, $p = 0.017$). Predator pilots, Predator selectees and T-38 graduates had significantly more time on target than any civilian group (p's from < 0.001 to 0.043).

These results show that even after the groups are all brought to a criterion level of stick-and-rudder ability to handle the simulated Predator aircraft, different types and amounts of flying experience still determine success on the Reconnaissance Task. Our analysis of Reconnaissance Task performance will provide evidence that this effect of pilot group is not due solely to residual differences in stick-and-rudder skills, but rather to some higher order cognitive skills required for maneuvering and maintaining orientation.

Summary. Both the overall trials-to-criterion data and the reconnaissance time-on-target data

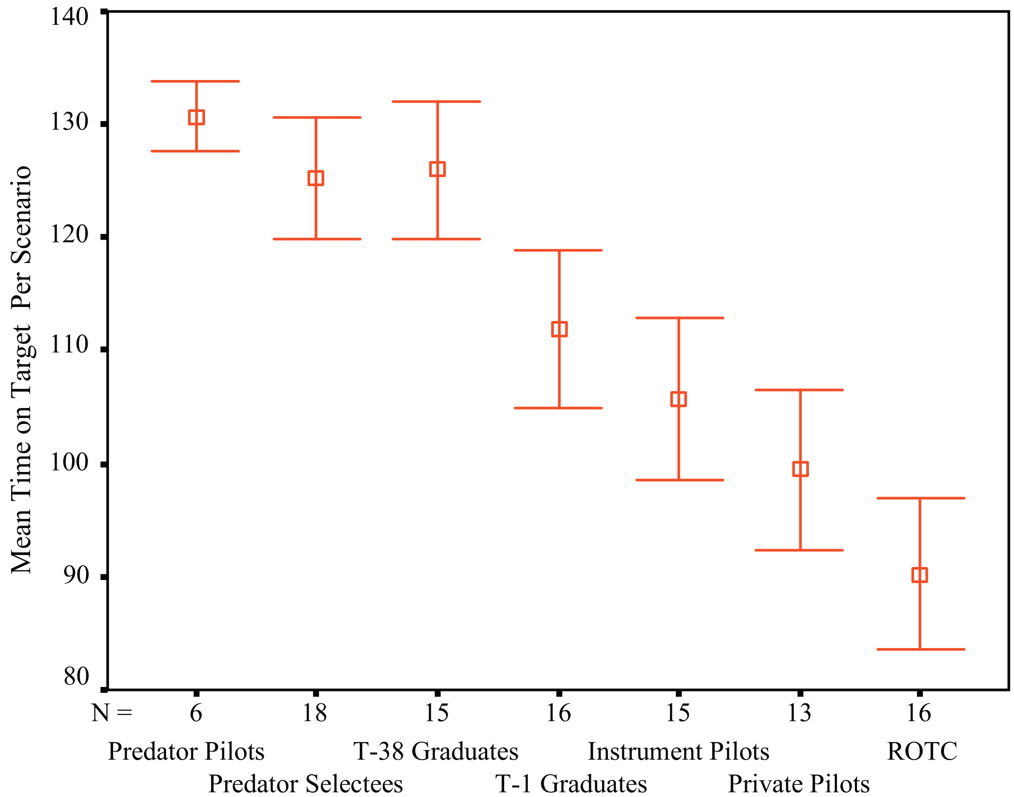

Figure 6. Time that the sensor camera was viewing the target through the cloud hole, and the aircraft was not in bank, depression angle, stall, altitude, or no-fly-zone violations.

suggest that, although the effect of pilot group (and therefore flying experience) is primary and highly significant, amount of prior flying time is not the only determinant of performance. Some groups do worse and others do better than would be expected on the basis of flying hours alone. Our analysis of performance on individual tasks will suggest some reasons for this.

Details of Performance on Individual Tasks

Basic Maneuvering Task

Figure 7 shows the mean total number of training trials required to pass all seven segments of the Basic Maneuvering Task. Here the effect of pilot group does not reach significance ($p = 0.074$). This task is not nearly as difficult as the Landing Task. It generally requires many fewer trials to pass. However, it was necessary to include the task so that nonpilots could learn to control the simulated aircraft and other non-Predator pilots could become familiar with the gauges and handling characteristics.

Although groups did not differ significantly in number of trials to criterion, they differed dramatically in more fine-grained measures of aircraft control. Figure 8 shows the normalized total RMS error in performing all seven segments of the task. This score represents how closely each pilot was able to keep the aircraft to the desired airspeed, heading, and altitude simultaneously, a measure of total flying deviation error on all three parameters. To compute this score, mean RMS error for each subject in airspeed, heading, and altitude was calculated. Then the error values on each of these parameters were normalized so they could be added together as z-scores, thus assuring that none of them were improperly weighted in the average. The resulting total flying deviation error z-scores show a highly significant

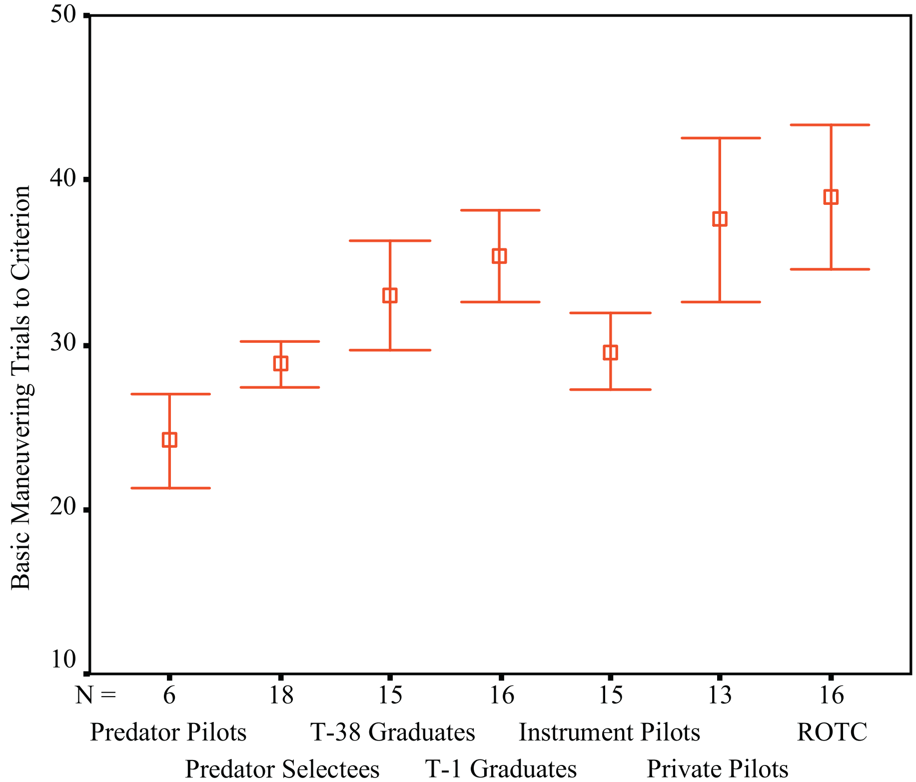

Figure 7. Number of trials required to achieve criterion performance on the Basic Maneuvering task.

effect of pilot group (p = 0.003). Figures 9, 10, and 11 show the raw RMS error scores. Clearly, error in airspeed and heading were the biggest contributors to differences between groups in overall error.

The pilot groups also differed in the variability and smoothness with which the simulated Predator was controlled. We computed two scores that are related to these characteristics. The variability score is called the standard variance composite, which was obtained by normalizing the variances of (absolute) pitch, bank, and rudder control values and summing them. The standard variance composite reflects the extent to which the participant made numerous control inputs. That is, frequent control inputs tend to produce a higher standard variance composite score. Similar to the standard variance composite, the rate variance composite reflects the smoothness of control rate inputs and is the normalized sum of variances in pitch, roll, and yaw rates. Large, quick control inputs tend to produce high rate variance composite scores. Figures 12 and 13 show these scores. For both variables, the effect of pilot group was highly significant (standard variance, $p = 0.002$; rate variance, $p < 0.001$). Predator pilots exhibited significantly less variable and smoother performance than the Predator pilot selectees (standard variance, $p = 0.046$; rate variance, $p = 0.003$), and the two civilian groups exhibited significantly lower variability and better smoothness scores than the two military pilot groups with comparable numbers of flight hours, i.e., T-38 and T-1 graduate (p-values from .001 to .028). This advantage for the civilian groups may be due to familiarity and recency of flying a small propeller aircraft.

Landing Task

Figure 14 shows the mean total number of training trials required to pass both the no-wind and crosswind landing trials. The overall effect of pilot group was highly significant ($p < .001$). ROTC students required significantly more trials than any other group. Predator pilots required significantly fewer trials than ROTC, private pilots, or T-1 graduates. Predator selectees and instrument pilots also

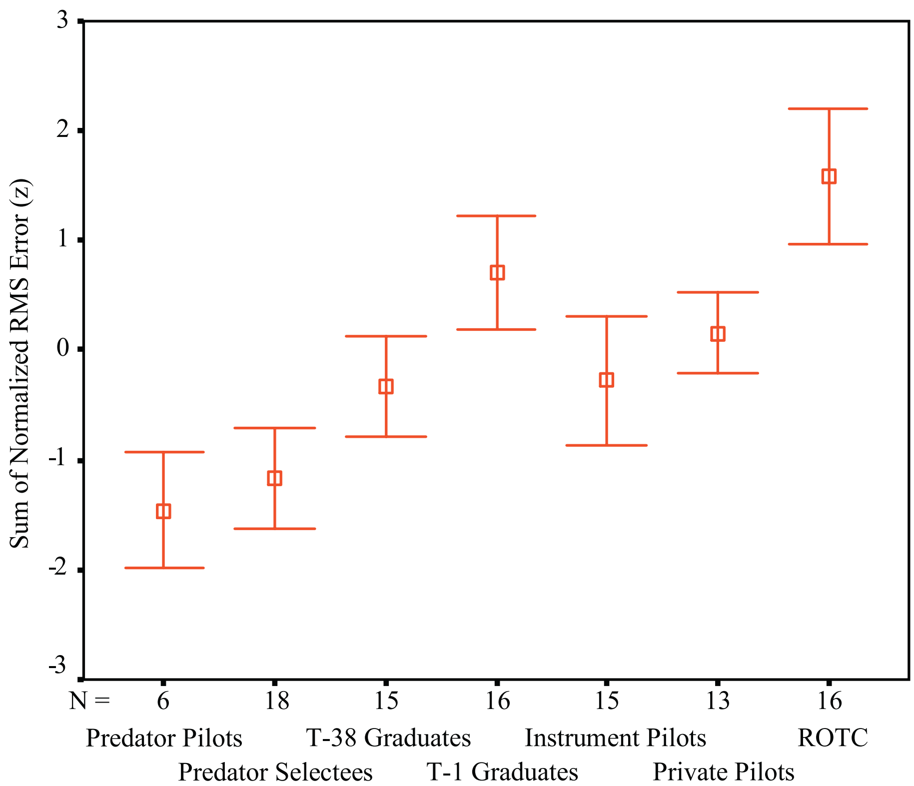

Figure 8. Sum of normalized RMS error scores on altitude, airspeed and heading parameters during performance of the Basic Maneuvering task.

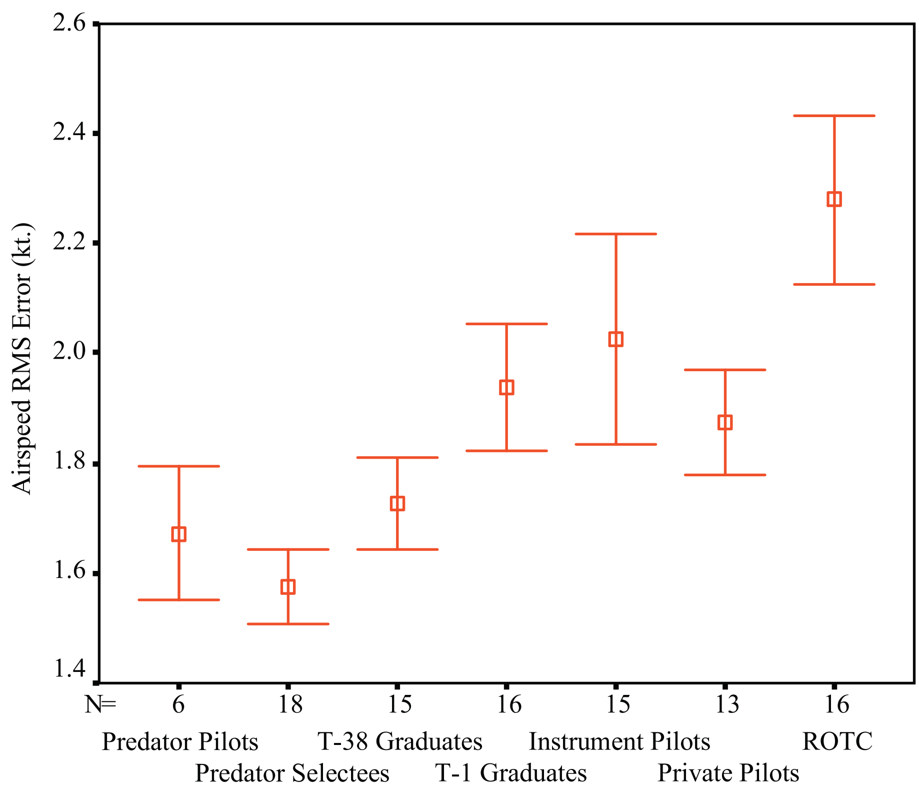

Figure 9. RMS error on the airspeed parameter in the Basic Maneuvering Task.

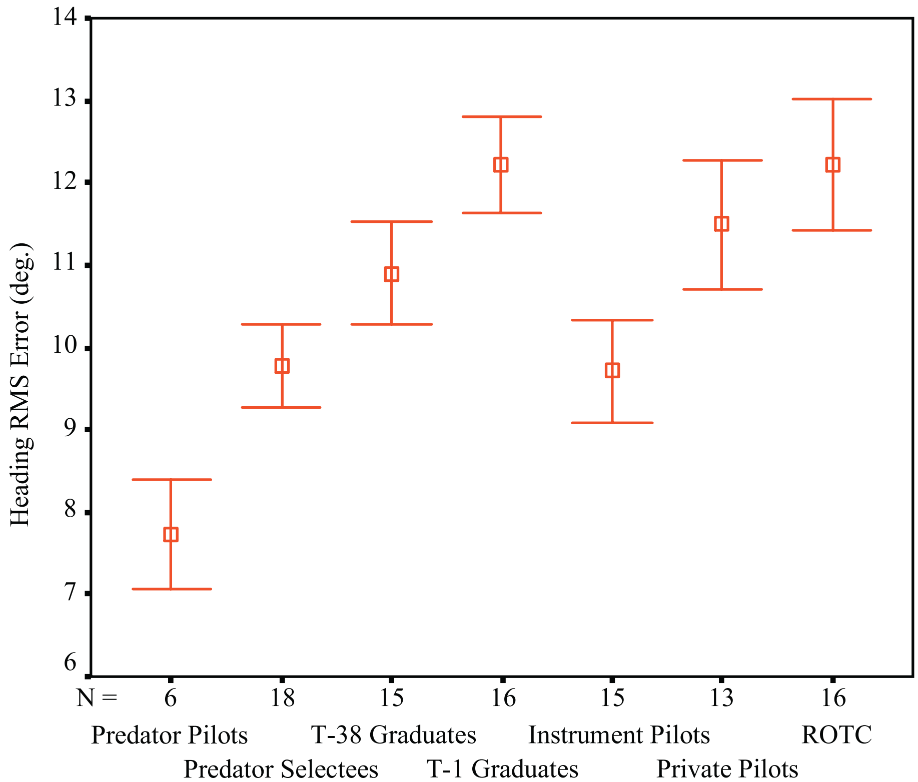

Figure 10. RMS error on the heading parameter in the Basic Maneuvering task.

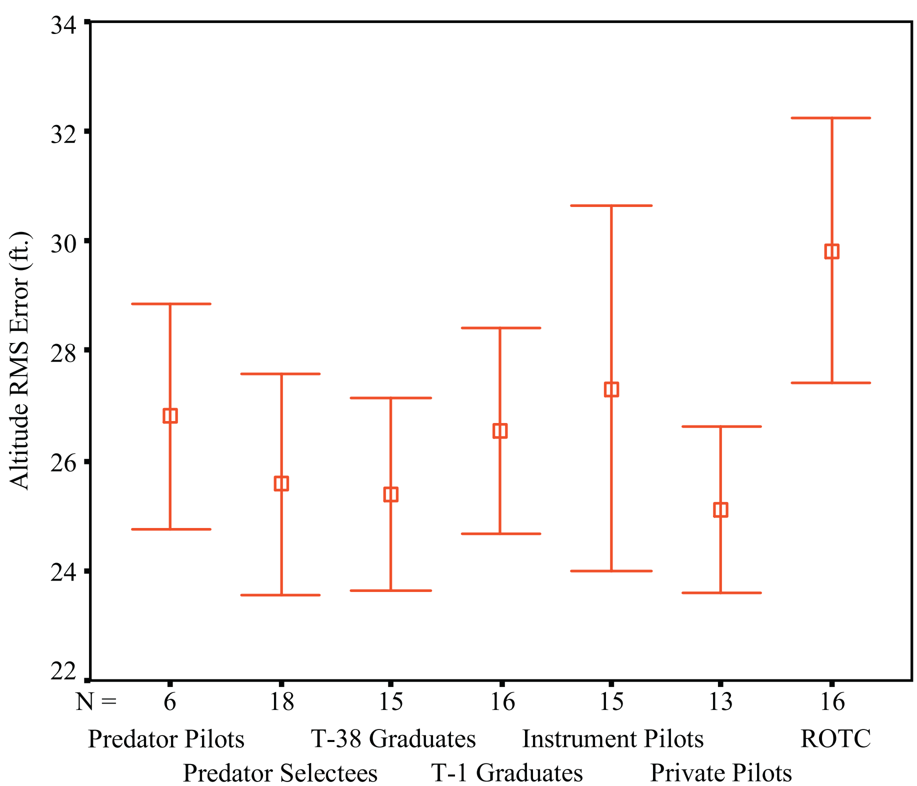

Figure 11. RMS error on the altitude parameter in the Basic Maneuvering task.

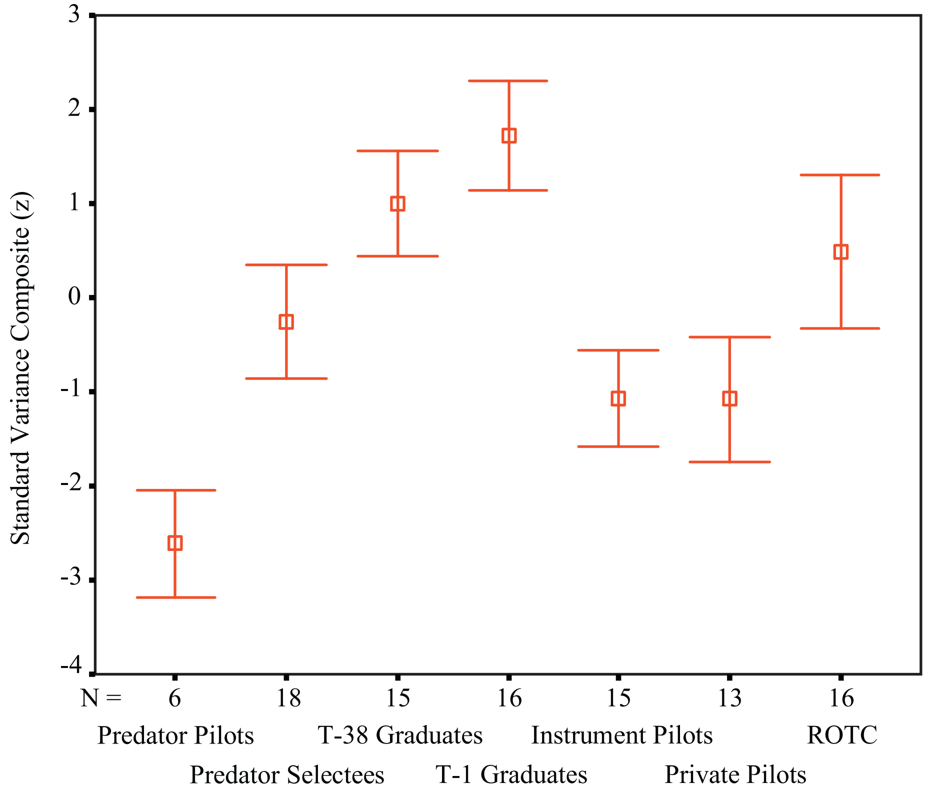

Figure 12. Standard variance composite score for the Basic Maneuvering task. Score is the normalized sum of variances in pitch, bank and rudder control. Higher scores represent more variation in the size of stick and rudder inputs.

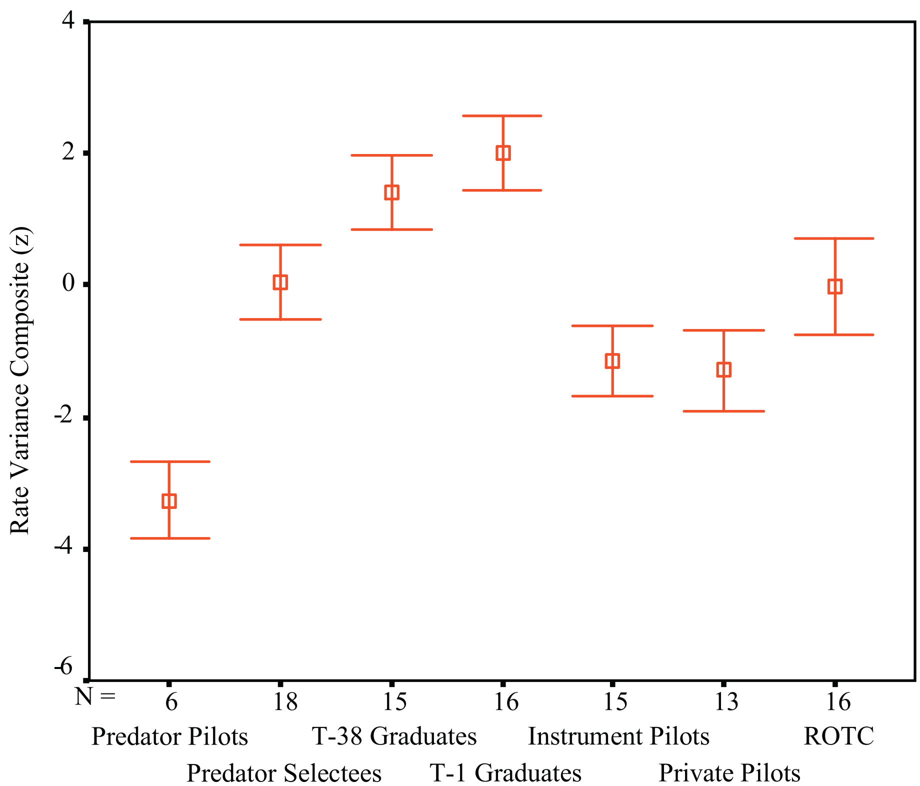

Figure 13. Standard rate variance composite score for the Basic Maneuvering task. Score is the normalized sum of variances in pitch rate, roll rate and yaw rate. Higher scores represent more variation in the rate of stick and rudder inputs.

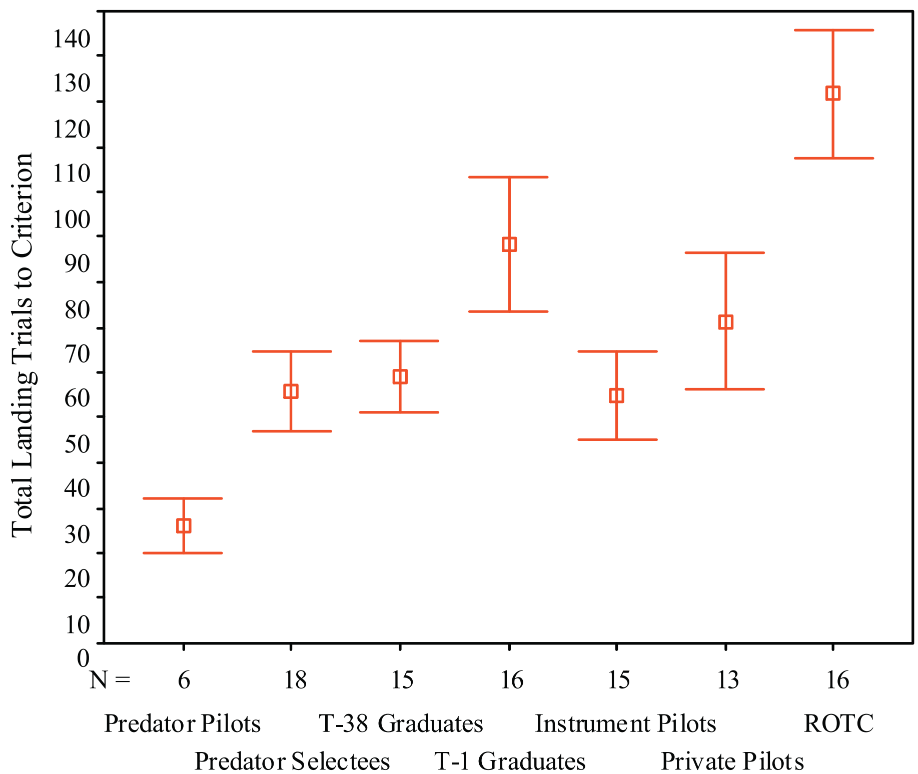

Figure 14. Total Number of Landing Trials to Reach Criterion.

required fewer trials than T-1 graduates ($p = 0.043$ and $p = 0.047$ respectively). It should be noted that to pass either the no-wind or the crosswind landing, the participant had to perform a perfect landing on all 13 required criteria simultaneously. This "perfect" landing criteria was a higher standard than even the experienced Predator pilots expected, hence even they required multiple attempts to achieve criterion. Had the criterion been lower, fewer attempts would have been necessary to pass, and our confidence in the task's ability to assess difficult cross-wind landings would have been reduced.

Dangerous Landings. Perhaps as important as the total trials to reach criterion performance are differences between groups on the number of potentially dangerous landings. A dangerous landing could be the result of a number of factors, such as nose-low, nose-high, wing-low, high lateral velocity, large distance off centerline, or hard touchdown. Here we report only those dimensions for which a sizable sample of dangerous landings was observed. Even though the database for analysis is substantially reduced to examine only these infrequent events, meaningful trends and significant results were still found between pilot groups.

Nose Wheel Landings. Figure 15 shows the significant ($p < .04$) effect of pilot group on the proportion of nose wheel landings, defined as landings in which the simulated aircraft's pitch was less than zero degrees at touchdown. This type of landing was usually the result of either a late/nonexistent flare or an early flare followed by a wing stall and subsequent "porpoise" landing. ROTC students had significantly more such landings than any other group except T-38 graduates (p-values range from < 0.01 to < 0.05). Private pilots also had significantly fewer nose wheel landings than T-38 graduates ($p = 0.038$).

Hard Landings. Figure 16 shows the proportion of hard landings, defined as landings with an instantaneous sink rate of 480 ft/min or greater at the moment the first wheel touched the runway. The overall effect of pilot group was significant ($p < .02$). Pairwise comparisons between the groups revealed that T-1 graduates had significantly more hard landings than all other groups except the Predator pilots

(p = .076) and the ROTC students (all p's < .01). One other pairwise comparison approached, but did not achieve, significance at the .05 level: private pilots performed fewer hard landings than the ROTC students (p = .063).

Dangerous Touchdown Heading. Landings with high heading deviation, crab, and/or high lateral velocity could result in excessive gear side-loading and/or potentially running off the side of the runway. These conditions are the result of either a large crab angle at touchdown and/or a velocity vector substantially misaligned with respect to the runway centerline. Figure 17 shows the proportion of landings in which the heading deviation at touchdown was unacceptably large (greater than 5 degrees). The overall effect of pilot group was significant (p < .01), largely due to the ROTC students' overwhelmingly poor heading deviation performance relative to all the other groups (all p's < .001). No other group pairwise comparisons were significant. Lateral velocity under wind conditions, shown in Figure 18 (upper line), should be related to heading deviations. As was the case with high heading deviation landings, ROTC students performed significantly worse (i.e., the highest average lateral velocity) than all other groups (all p's < .02), while all other group pairwise comparisons were not significant.

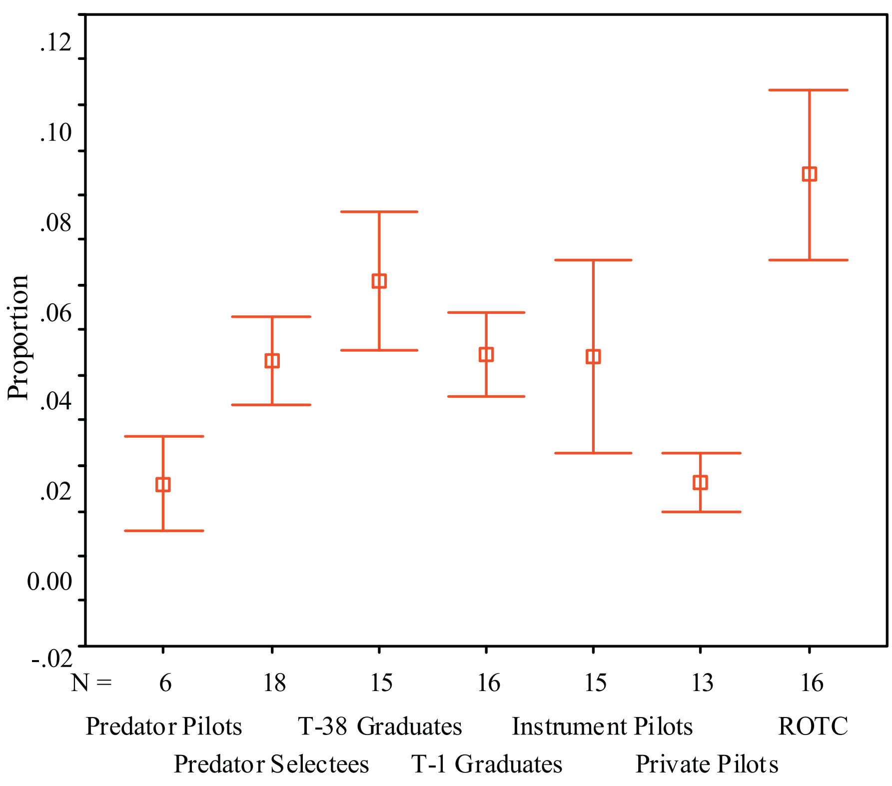

Figure 15. Proportion of Nose-Wheel First Landings.

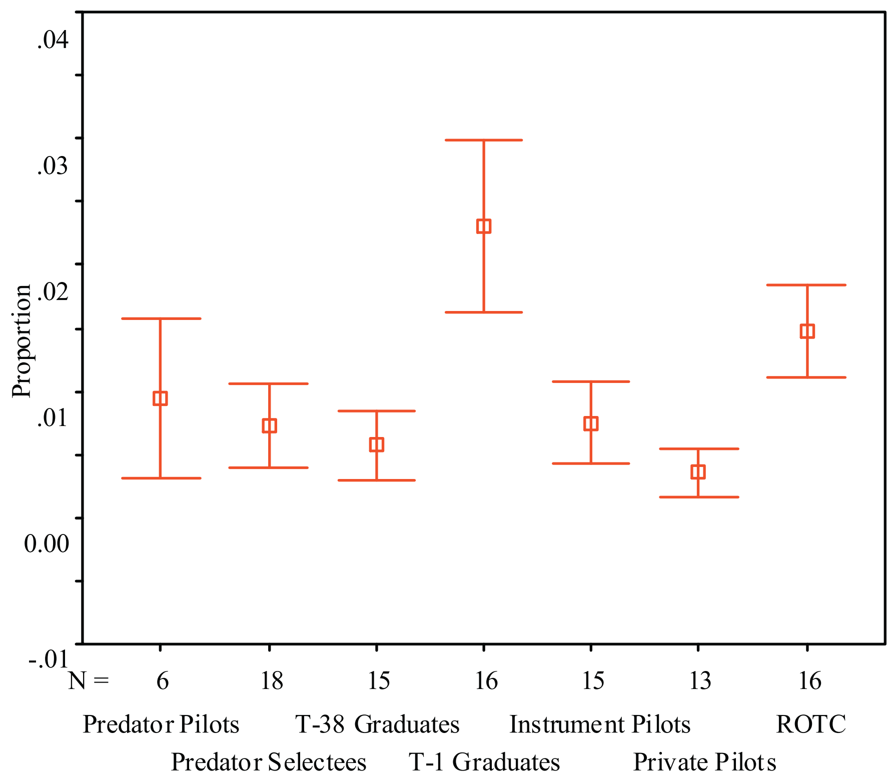

Figure 16. Proportion of Hard Landings. A hard landing was defined as an instantaneous sink rate at the moment of touchdown exceeding 480 feet per minute.

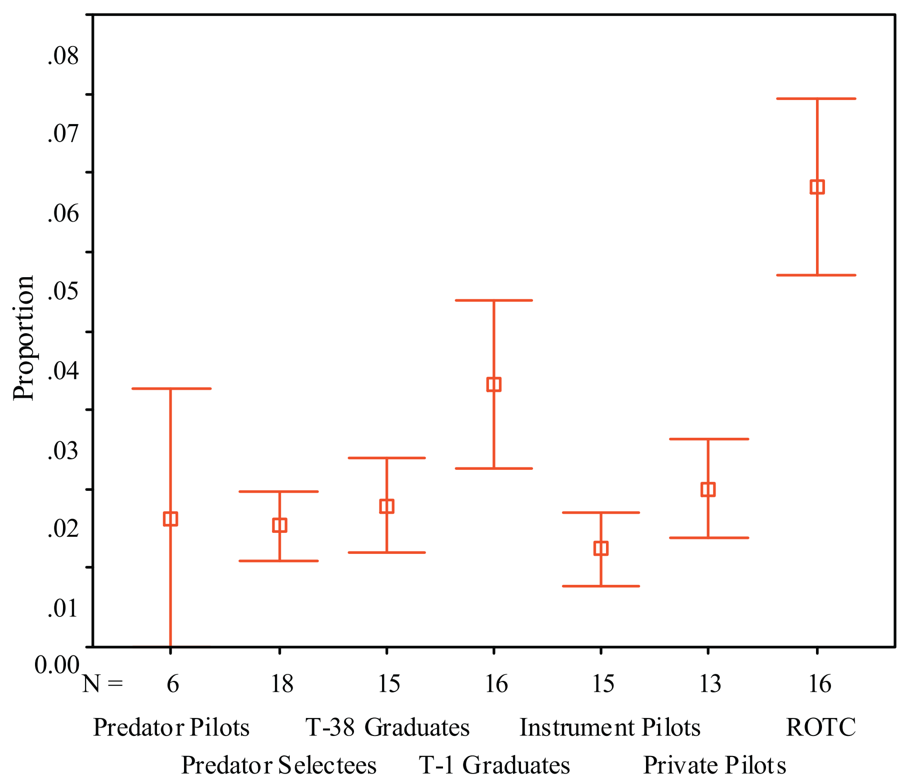

Figure 17. Proportion of High Heading Deviation Landings. A high heading deviation was defined as an absolute heading at touchdown greater than five degrees off of the runway heading.

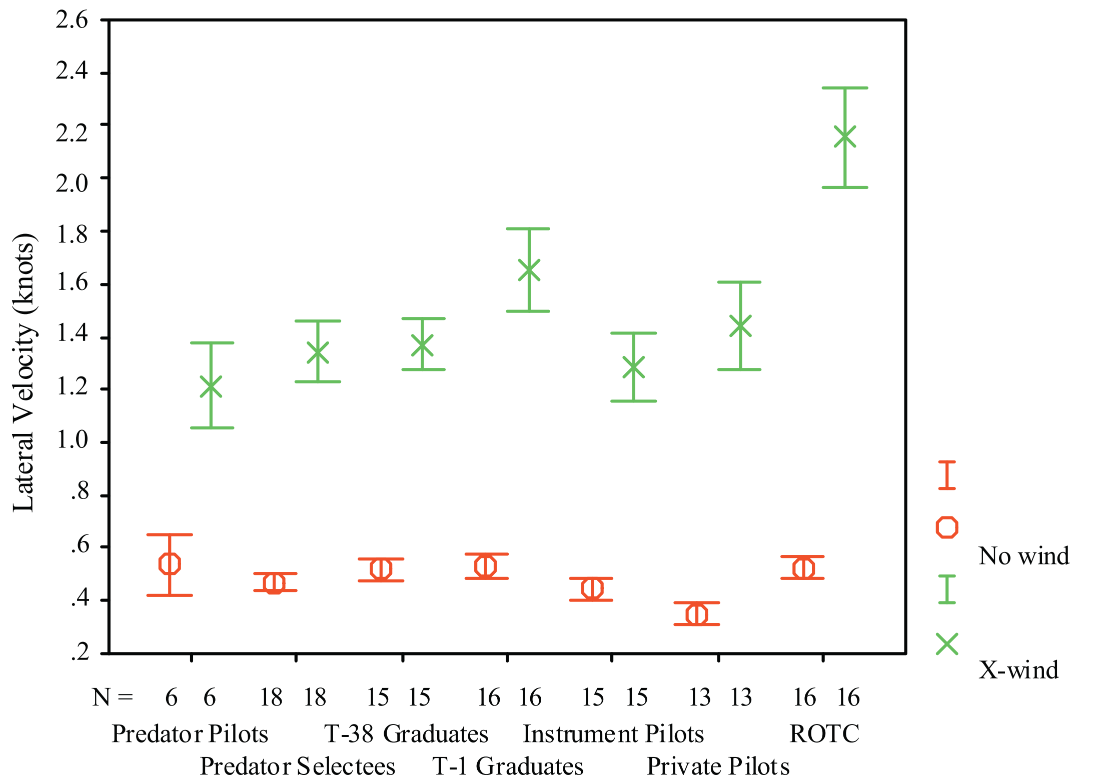

Figure 18. Lateral Velocity at Touch-down. Lateral Velocity reported here was the direct 90-degree velocity vector to the runway heading.

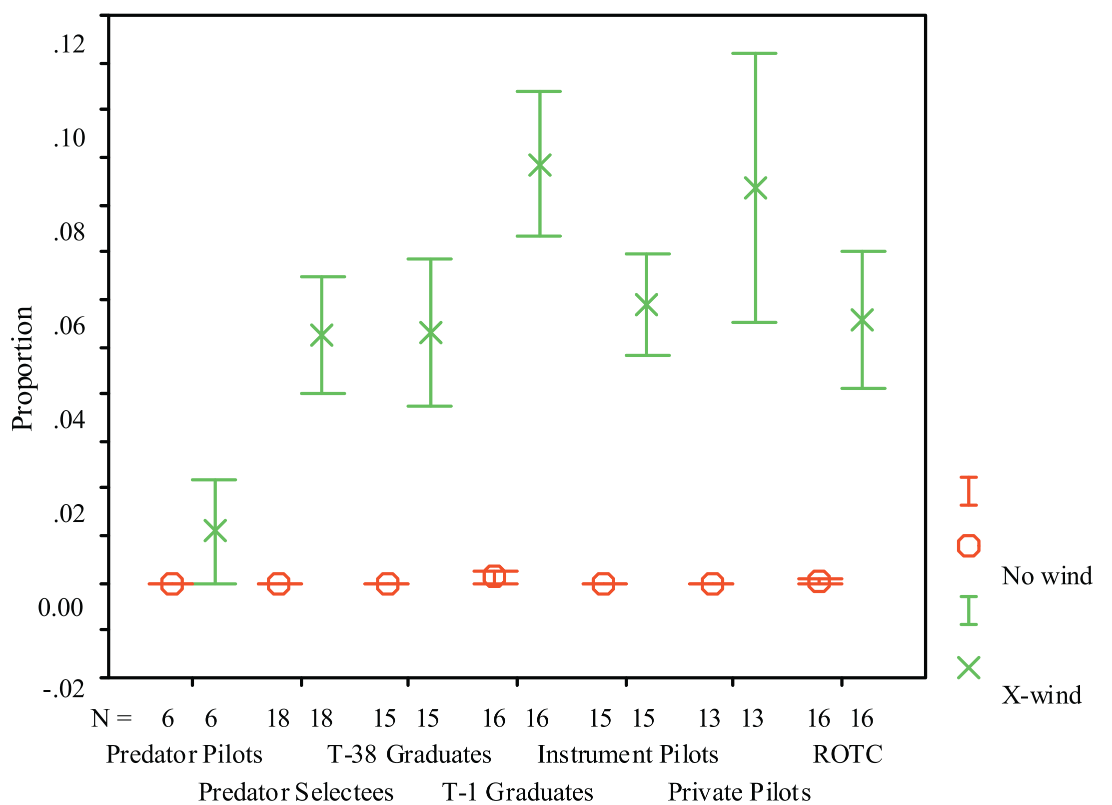

Figure 19. Proportion of Wing-Low Landings. A wing-low landing was defined as a bank angle greater than seven degrees at the moment of touchdown.

Wing-Low Landings. Figure 19 shows the proportion of wing-low landings, in which the bank at touchdown was greater than seven degrees. Both wing-low and high-lateral-velocity landings occurred predominately on trials with wind. Though the overall effect of pilot group regarding wing-low landings was not significant, Predator pilots performed very few wing-low landings, while landings with crosswind for all other groups resulted in wing-low landings 5% or more of the time. It is possible that the non-Predator-pilot groups had more difficulty coordinating the interaction of bank, rudder, and crab with the responsive Predator UAV.

Landing Phases. To further explore group differences in landing performance, we separated the landing into phases—pattern, final approach, roundout/flare, and touchdown. Because the downwind and base legs of the approach pattern are quickly learned and are relatively easy to fly, results show no important differences between groups in either the pattern RMS or pattern altitude gate measures; that is, a ceiling effect was found where all groups consistently performed at or better than criterion level. Differences between the groups on the Landing Task became apparent during the more difficult stages (final approach through touchdown), especially between the extreme ends of the experience continuum (Predator pilots and ROTC students).

Compared to other groups on final approach, Predator pilots are far more precise, having the smallest groundtrack and glideslope error, maintaining the most constant airspeed and VSI rates, and having significantly more stable flight characteristics, that is, lower variability and better smoothness scores (p-values range from 0.001 to 0.02). Figures 20, 21, 22, and 23 compare the groups on the major final approach groundtrack/glideslope measures. Figures 24 and 25 show variability and smoothness scores for the final approach phase.

Group differences in performance continue to develop during the roundout/flare phase. In particular, Predator pilots perform the roundout/flare differently than other groups. They do a more aggressive, distinct roundout/flare by waiting longer before rounding out pitch, but flying less distance when just above the runway. Figure 26 shows the large difference in distance flown when the aircraft is under 4-ft above ground level (AGL). Predator pilots perform the distinct roundout and flare by holding higher airspeeds and greater sink rates longer, waiting until they are closer to the runway, yet are able to bleed off this speed and sink rate quickly to touch down the softest. This is shown in Figures 27, 28, 29, 30, and 31, which show the mean vertical sink indicator (VSI) at 15-ft AGL, 10 ft, 5 ft, under 4 ft, and the instantaneous sink rate at touchdown, respectively. Finally, as was the case for final approach, Predator pilots demonstrate more stable flight characteristics during roundout and flare. The same variability and smoothness trends as those found for the glideslope phase (Figures 24 and 25) were found for the landing attitude phase (under 4-ft AGL), but unlike for glideslope, the groups overall did not differ significantly in variability and smoothness while in a landing attitude under 4-ft AGL.

At touchdown, predator pilots continue to show better performance. They have the lowest sink rate, pitch angle, and lateral velocity of any of the groups. By contrast the ROTC nonpilots are markedly worse on many touchdown parameters than the other groups. In particular, they touch down with the highest lateral velocity (Figure 18), the greatest distance from centerline (Figure 32), and the highest heading deviation (Figure 33). These problems arise largely during landings in crosswind.

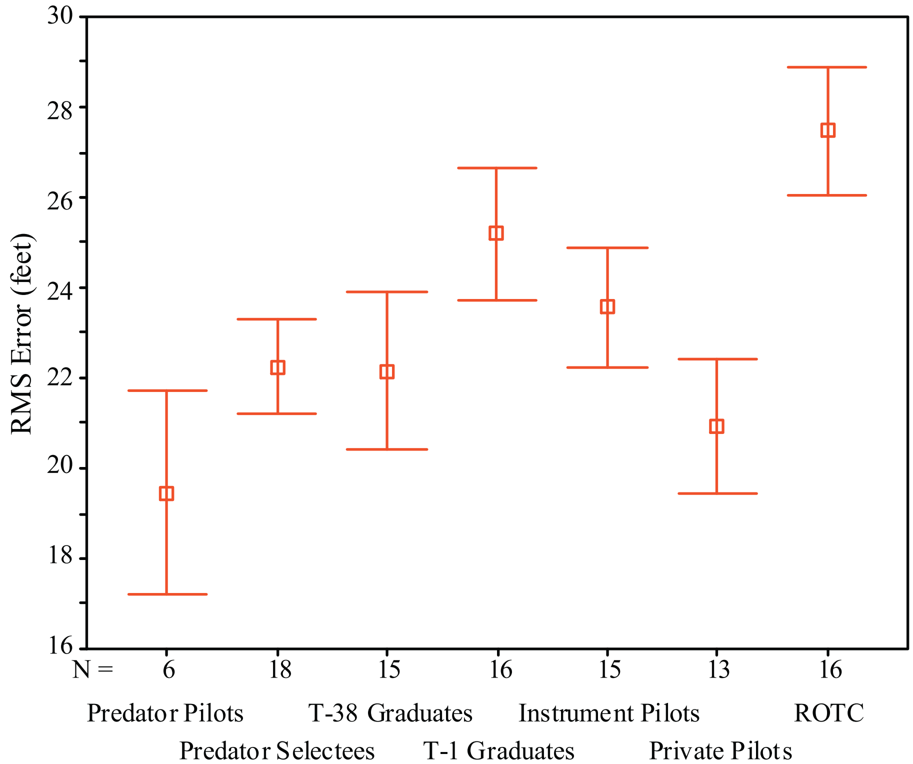

Figure 20. Final Approach Groundtrack RMS Error.

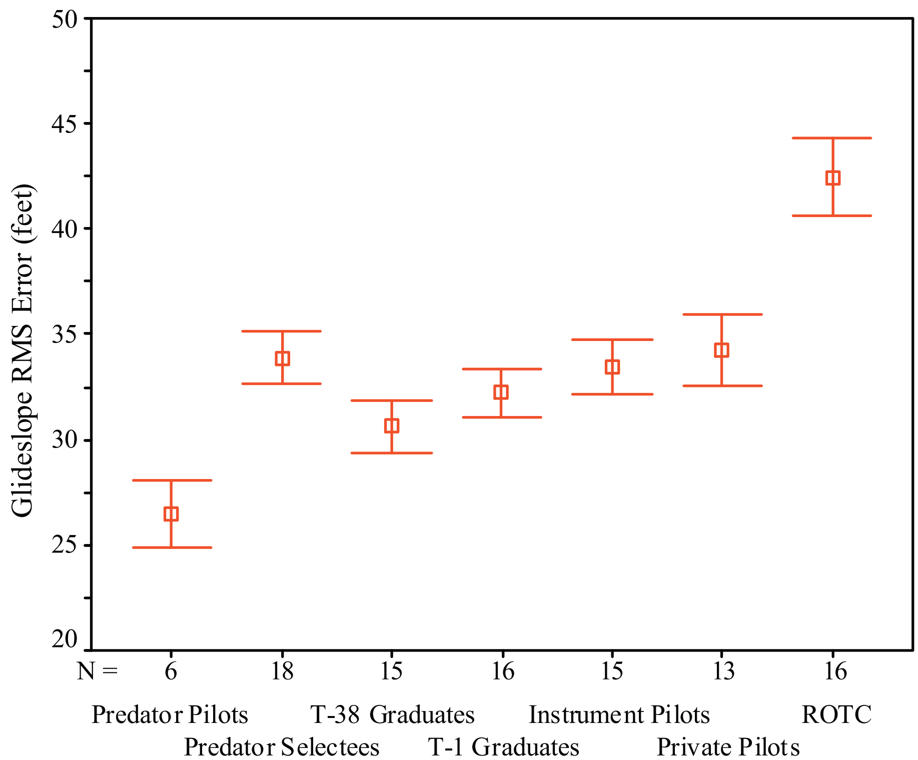

Figure 21. Glideslope RMS Error.

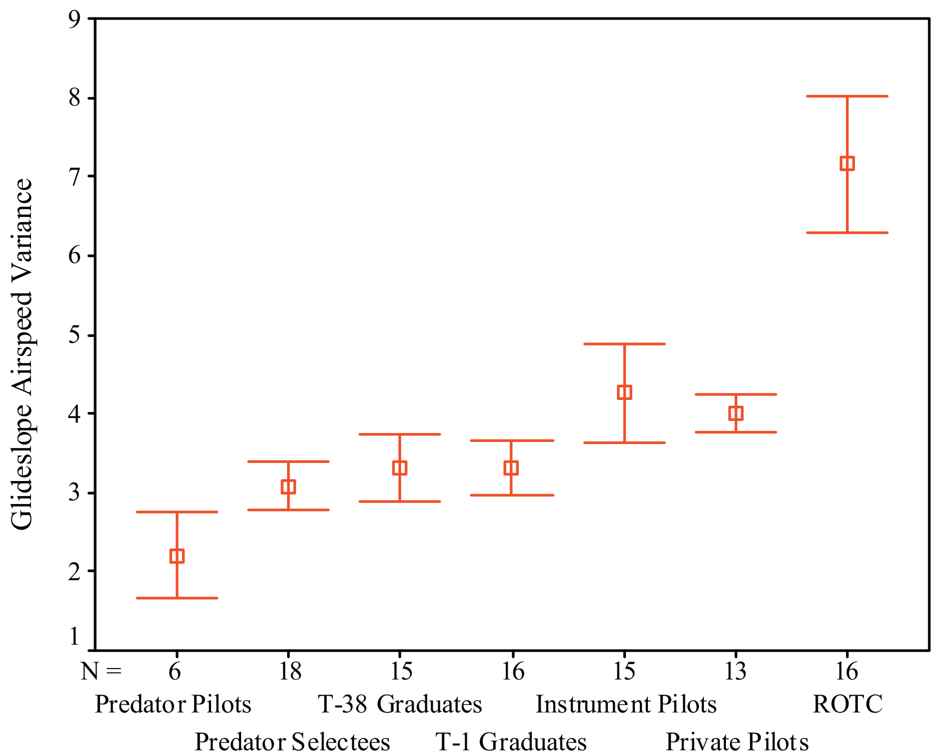

Figure 22. Glideslope Airspeed Variance.

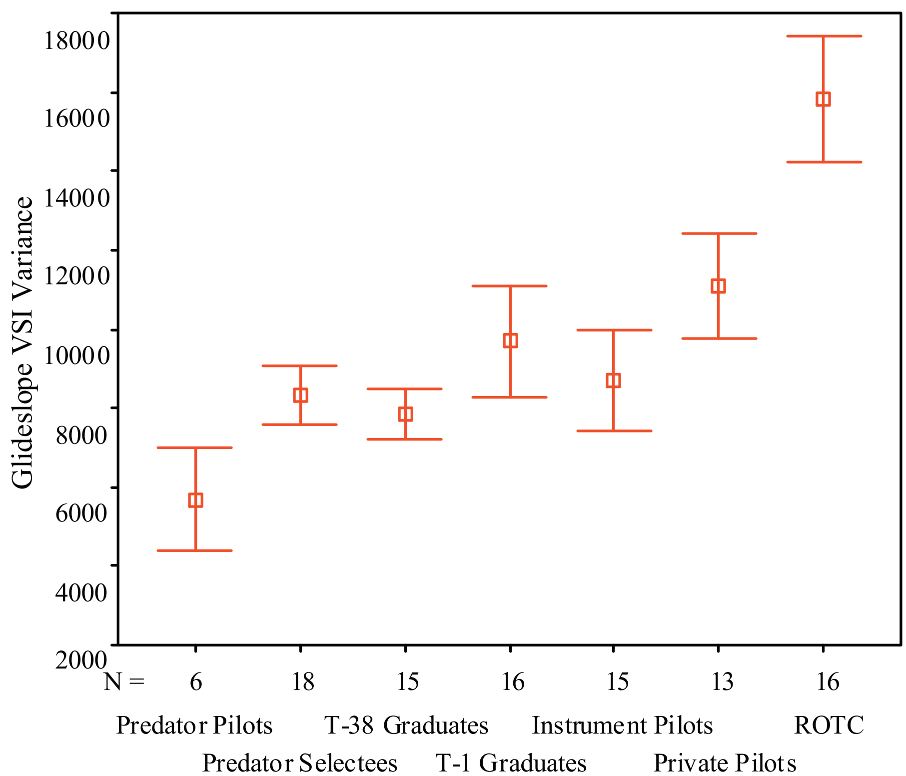

Figure 23. Glideslope VSI Variance.

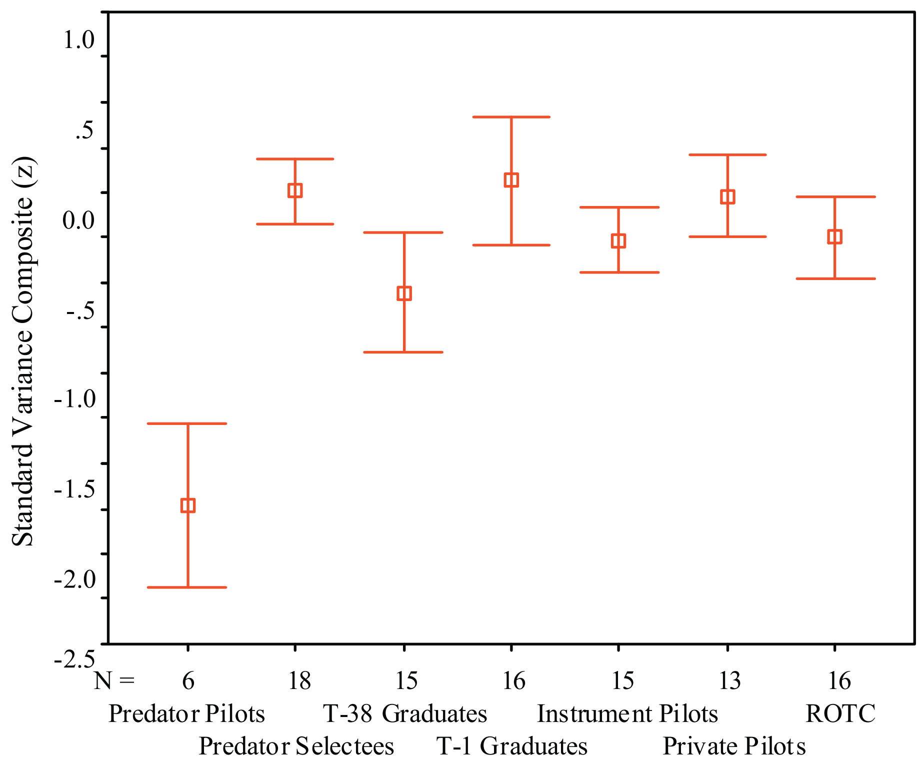

Figure 24. Glideslope Standard Variance Composite.

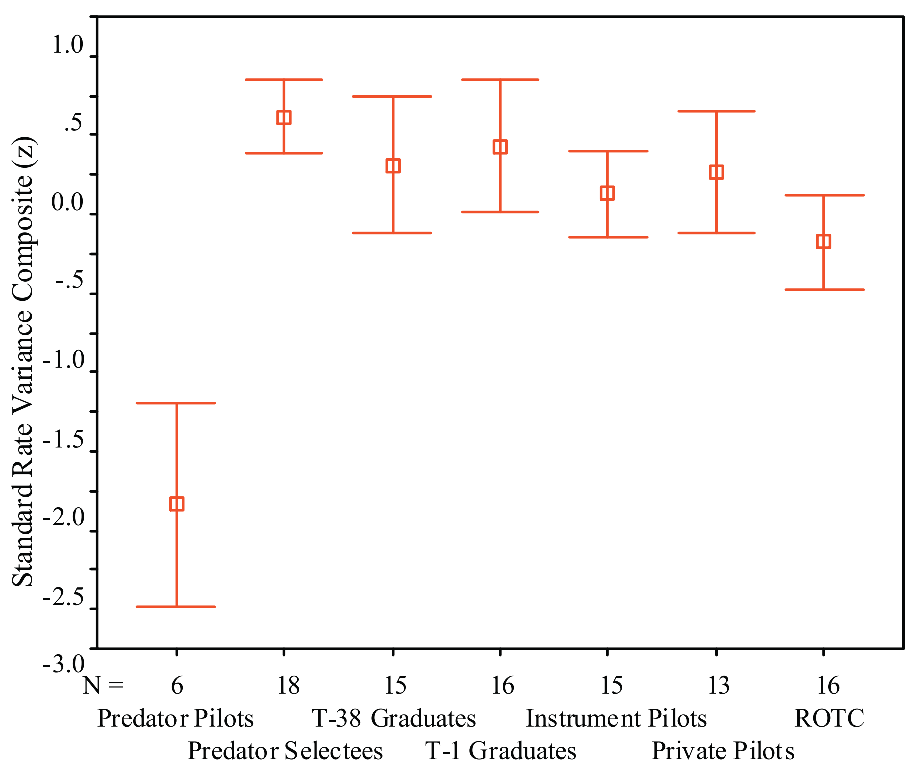

Figure 25. Glideslope Standard Rate Variance Composite.

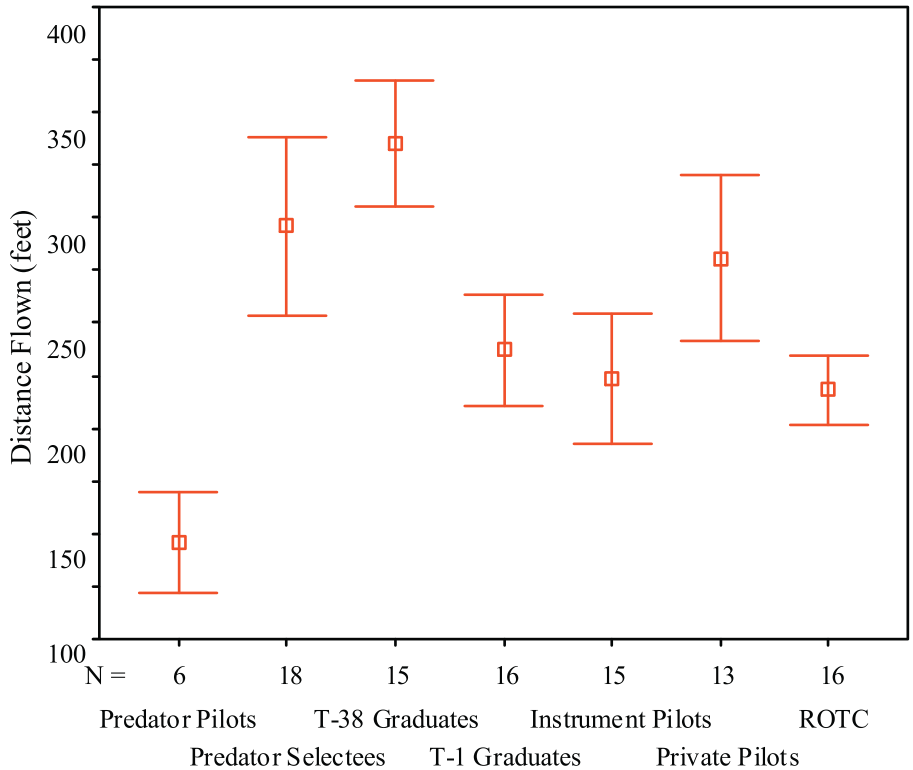

Figure 26. Distance Flown Under Four Feet Above Runway (AGL).

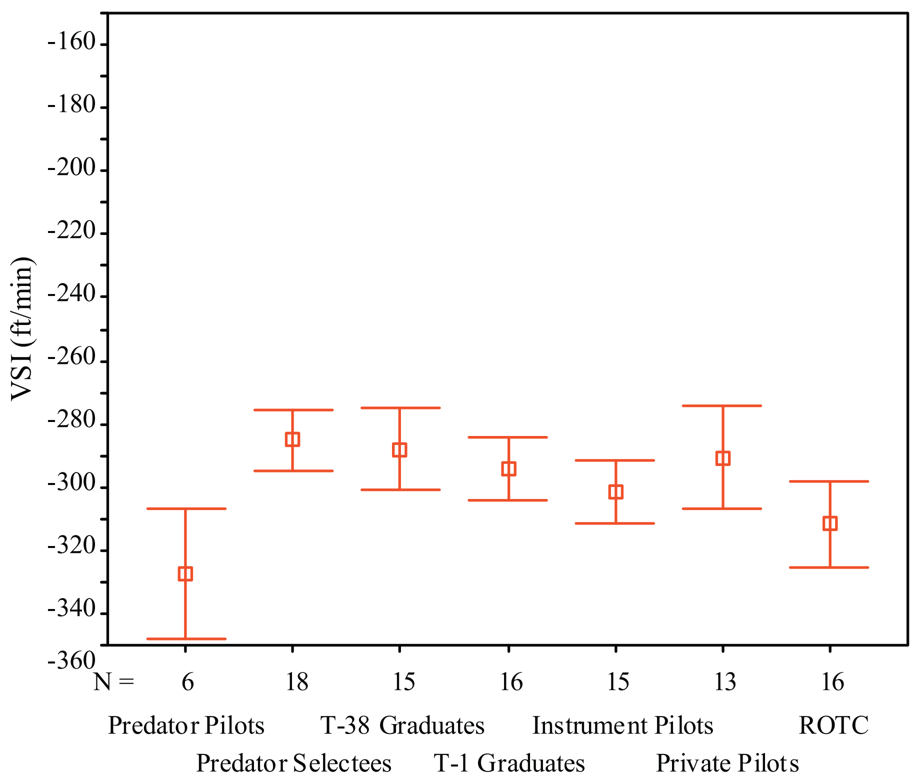

Figure 27. VSI at 15 Feet AGL.

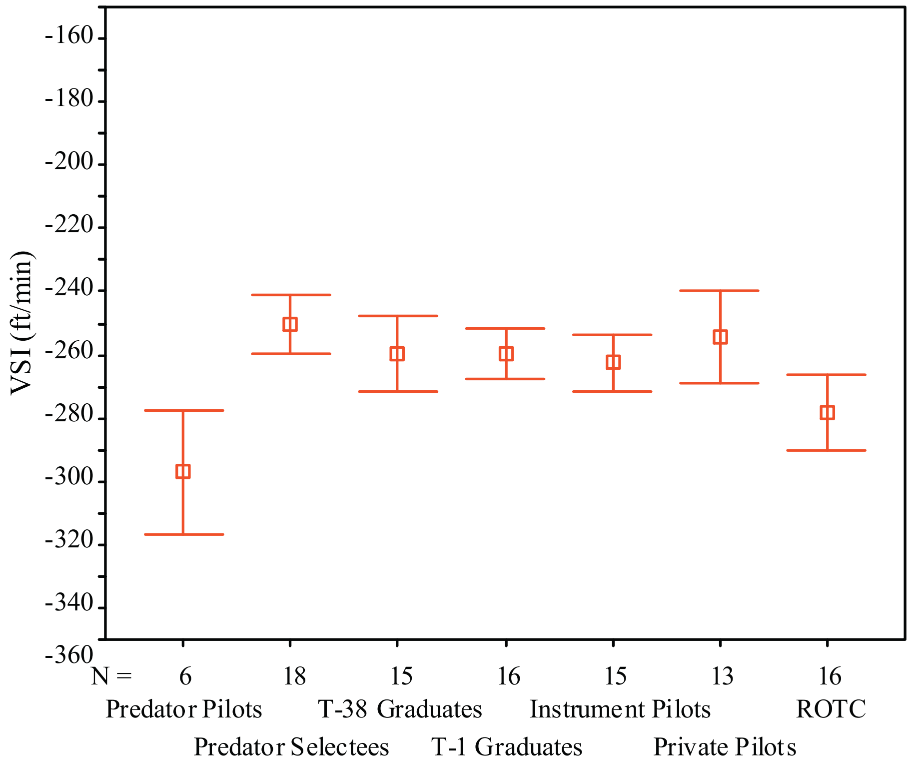

Figure 28. VSI at 10 Feet AGL.

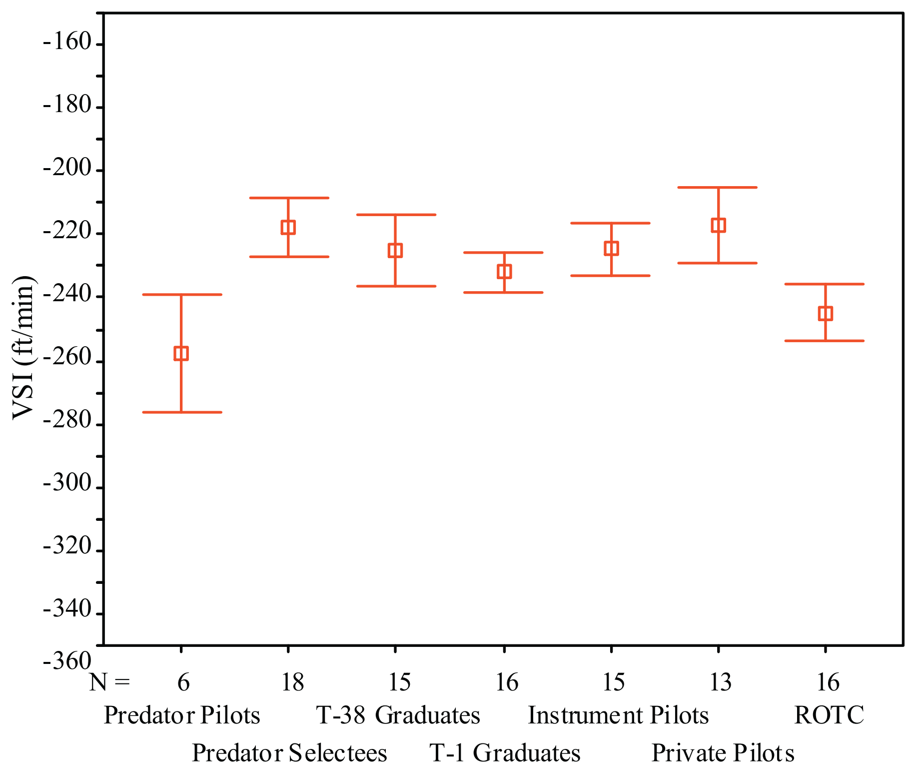

Figure 29. VSI at 5 Feet AGL.

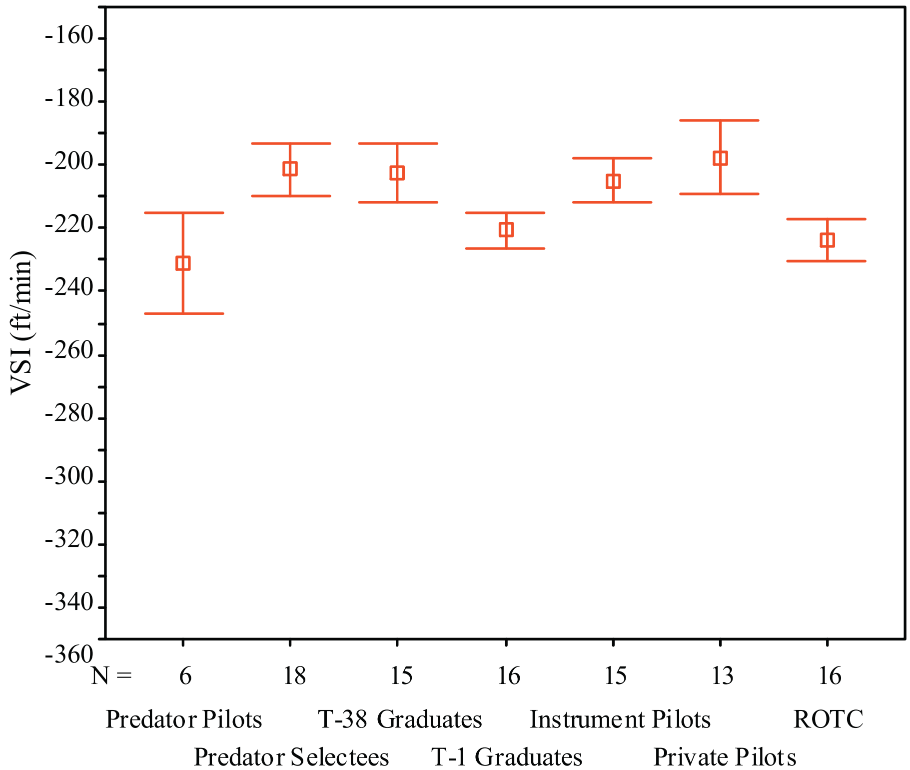

Figure 30. VSI Under 4 Feet AGL.

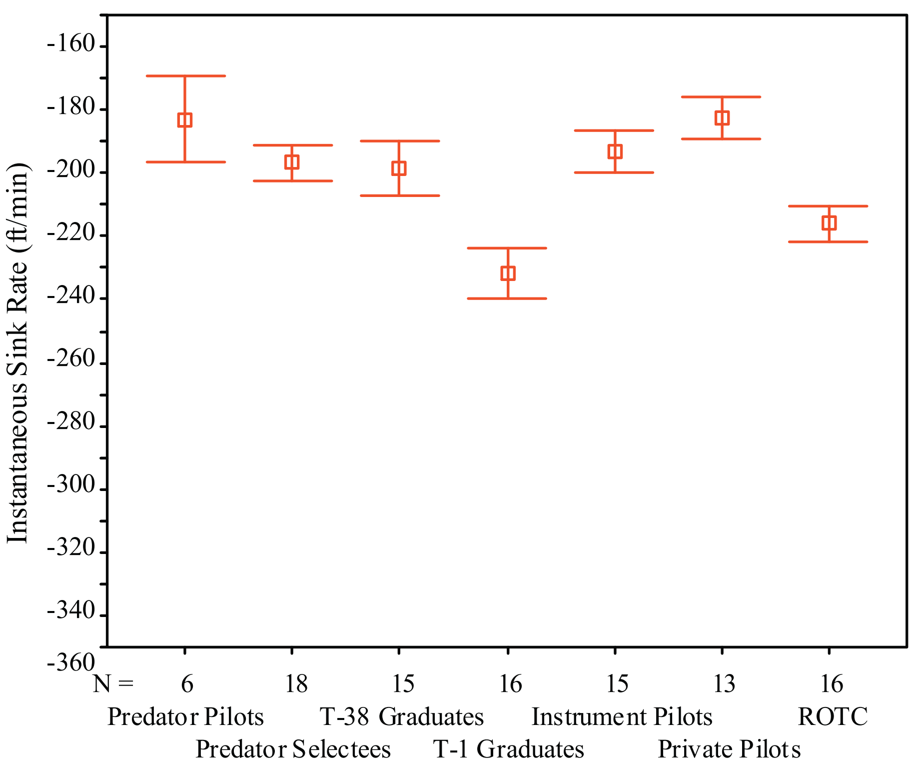

Figure 31. Instantaneous Sink Rate at Touchdown.

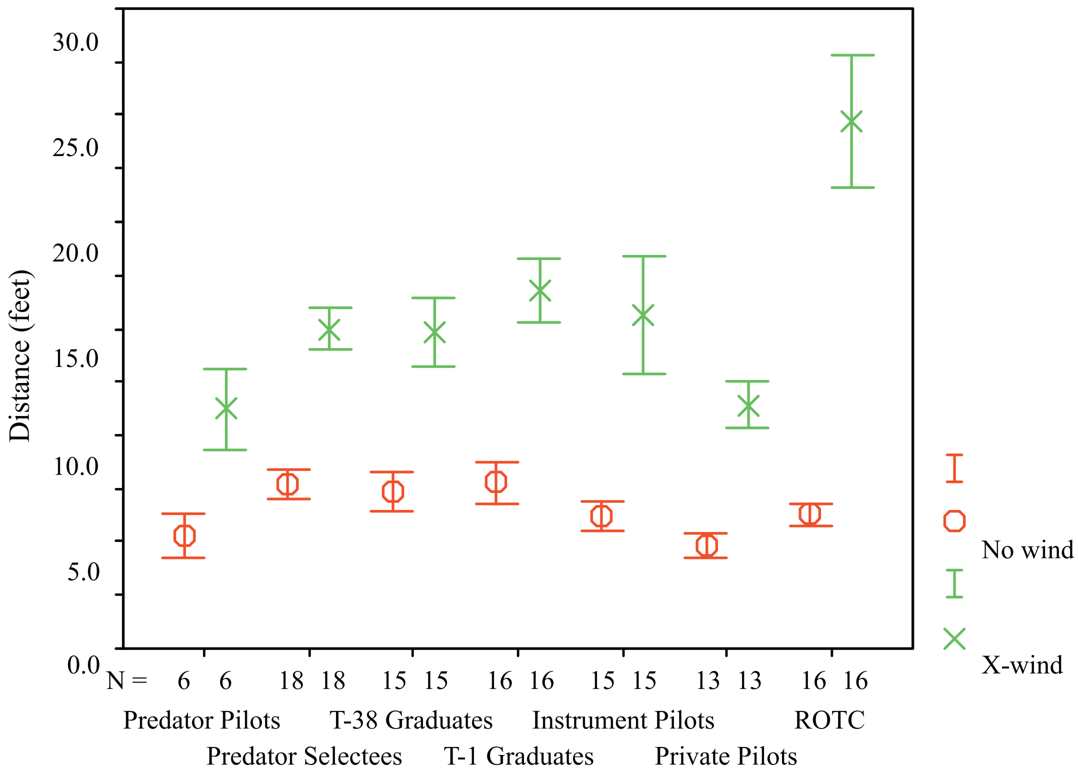

Figure 32. Distance Off of Runway Centerline at Touchdown.

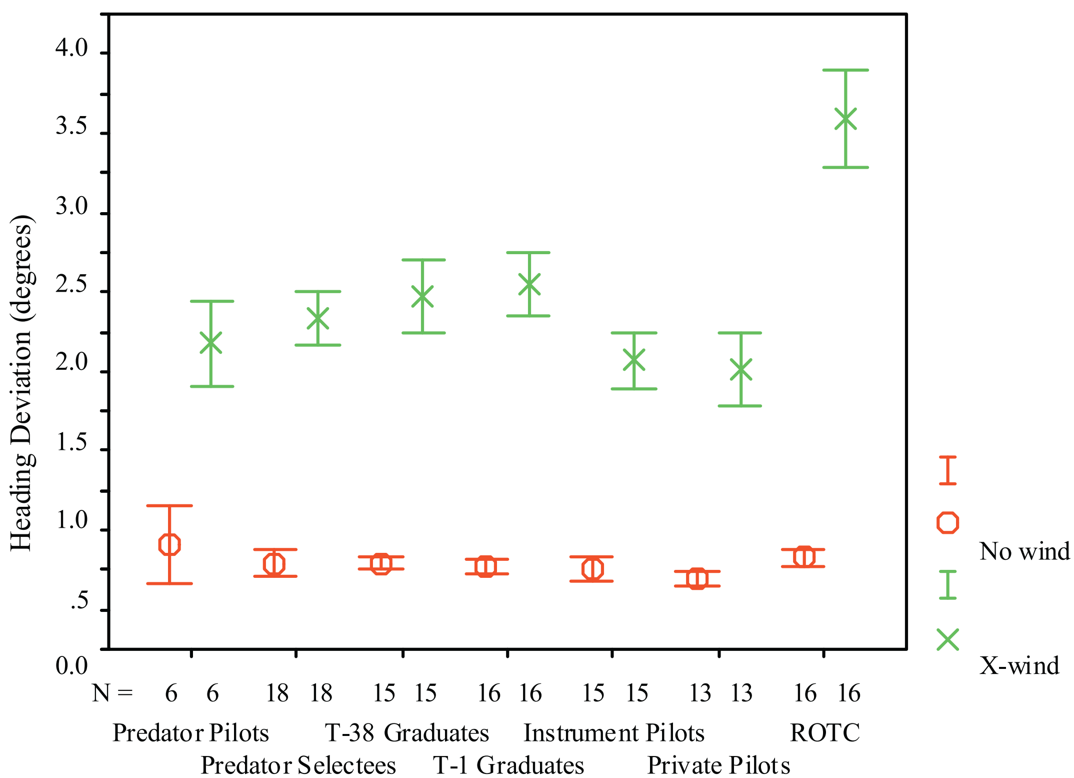

Figure 33. Absolute Heading Deviation From Runway Centerline at the Moment of Touchdown.

The fact that Predator pilots are superior in so many of these detailed comparisons at different phases of the Landing Task confirms the validity of the Predator aircraft simulation underlying these tasks. The differences observed between the Predator pilots and the Predator selectees—both highly experienced military pilots differing primarily in Predator experience—must therefore be attributable to the Predator-specific landing skills that the Landing Task demands.

Reconnaissance Task

The overall result for the Reconnaissance Task was presented in Figure 6. As stated earlier, the effect of pilot group was highly significant. Predator pilots obtained the most time on target, but not significantly more than selectees and T-38 graduates. These three groups obtained significantly more time on target than did civilian pilots and nonpilots. Further analysis shows some of the factors that underlie the strong effect of pilot group on this task.

Overall time on target in the Reconnaissance Task is determined by two things: (a) the amount of target viewing time during each "pass" through the target-viewable area, and (2) the number of passes through the target-viewable area that can be accomplished during each 10-minute trial. Although the general effect of pilot group was evident in both of these factors, there were some key differences in the pattern of results.

Time per pass. Figure 34 shows the mean amount of time per pass through the target-viewable area. The overall effect of pilot group was highly significant ($p < 0.001$) and the pattern is generally similar to the overall time on target results, except that Predator pilots had less (but not significantly less) time per pass than either selectees or T-38 graduates.

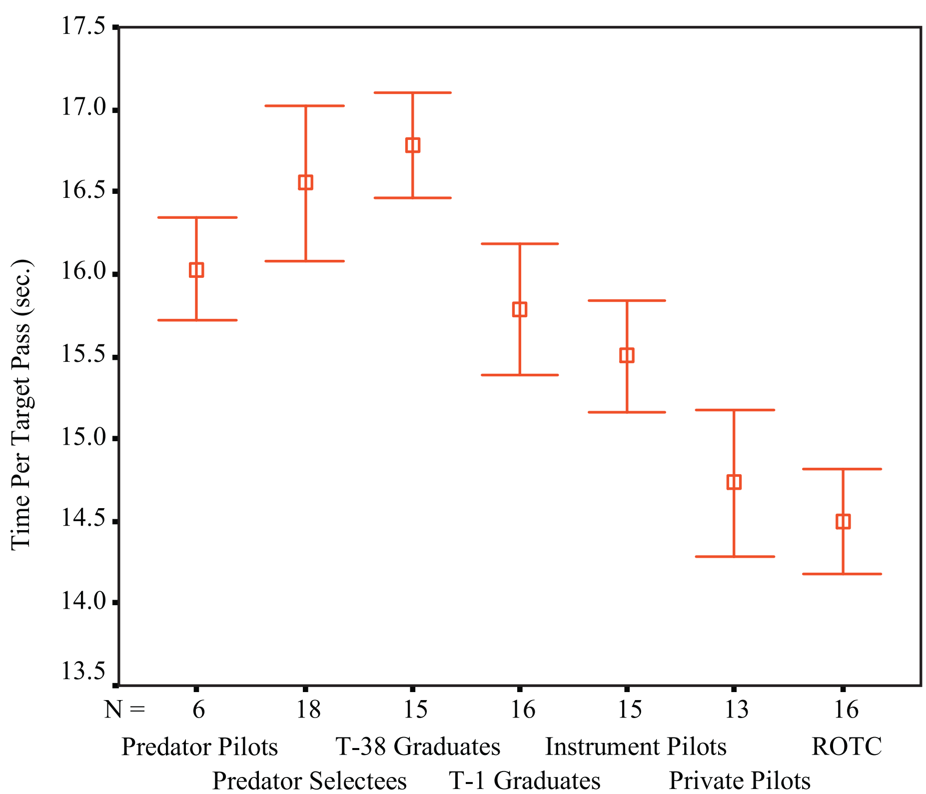

Figure 34. Time on target in the Reconnaissance task per pass through the target viewing area.

More time per pass can be obtained in a number of ways. The data suggest that two primary methods used by some pilots were (a) slowing down in the target-viewable area; and (b) climbing higher so that the target-viewable area is larger. The data show that Predator pilots were no more likely to avail themselves of these methods than were selectees and T-38 graduates. Figures 35 and 36 show mean airspeed and altitude while the aircraft was in the target-viewable area. Overall effect of pilot group was significant for both of these variables (airspeed, $p < 0.001$; altitude $p = 0.026$). It is possible that Predator pilots did not consider large changes in altitude and airspeed in the target area to be a realistic strategy, one that they would use during a real mission. So, for them, time per pass may not be a valid indicator of skill.

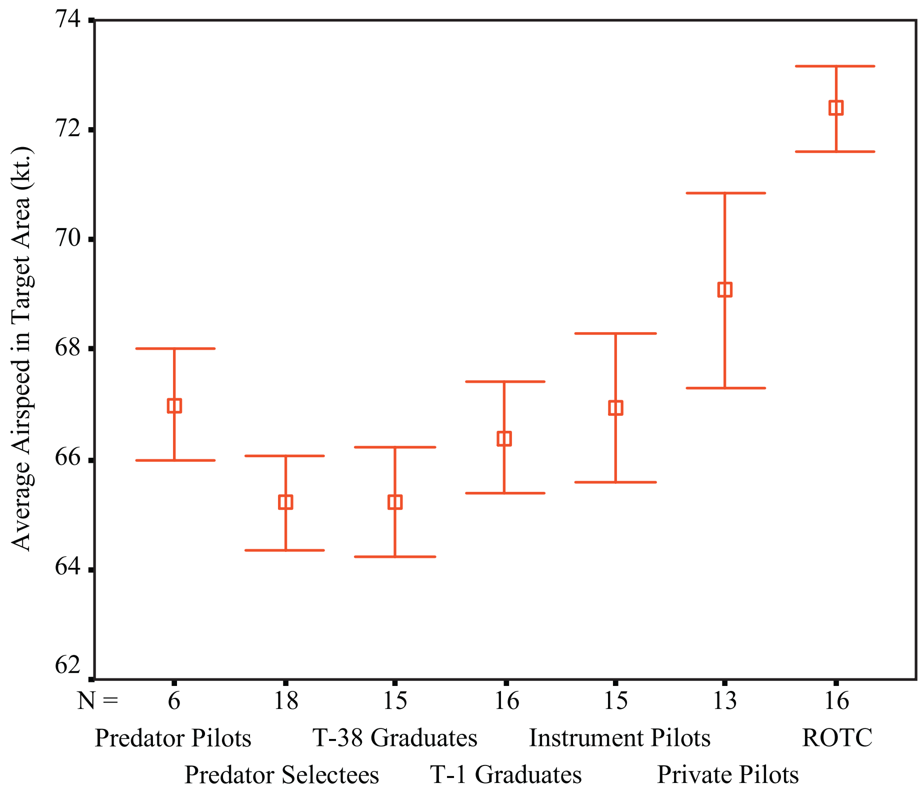

Figure 35. Average airspeed while in the target viewing area in the Reconnaissance task.

Number of passes. The reason that Predator pilots got the most overall time on target despite having less time per pass than some other groups is that they achieved more passes through the target viewable area. Figure 37 shows the data on number of passes. The effect of pilot group was significant ($p = 0.016$). Predator pilots got significantly more target area passes than any of the civilian groups. There are at least two reasons for differences in number of passes. First, it is clear that maneuvering more aggressively when outside the target-viewing area can allow the pilot to more quickly return to the target area. Several variables were indicative of aggressive maneuvering outside the target area (e.g., mean absolute bank angle, rudder inputs). Figure 38 shows group comparisons on one such variable, mean yaw rate outside the target-viewable area. The overall effect of pilot group on this variable was highly significant ($p = 0.004$), with Predator pilots having the highest mean yaw rate.

A second reason for getting more passes on the target was that some pilots seemed to be particularly good at figuring out where the target-viewable area would be and staying oriented with respect to this area. This ability was reflected in the number of times that pilots had to switch out of target camera mode to get a look around with the nose camera. Figure 39 shows the data on the number of target-to-nose camera switches per scenario. Predator pilots switch to the nose camera less than half as many times as any other group.

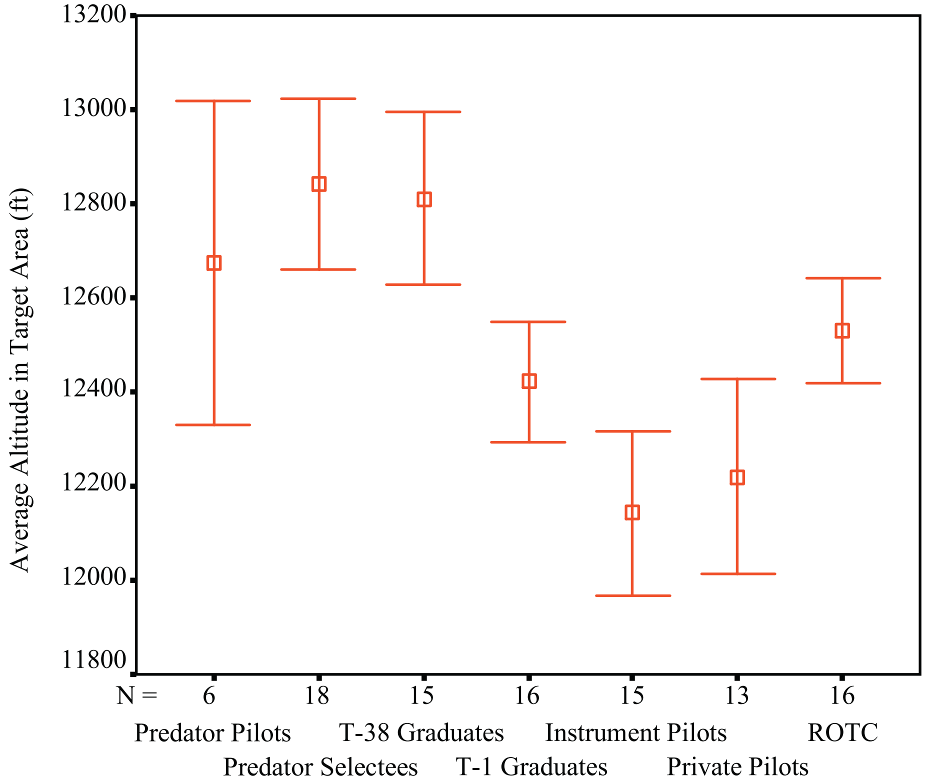

Figure 36. Average altitude in the target viewing area in the Reconnaissance task.

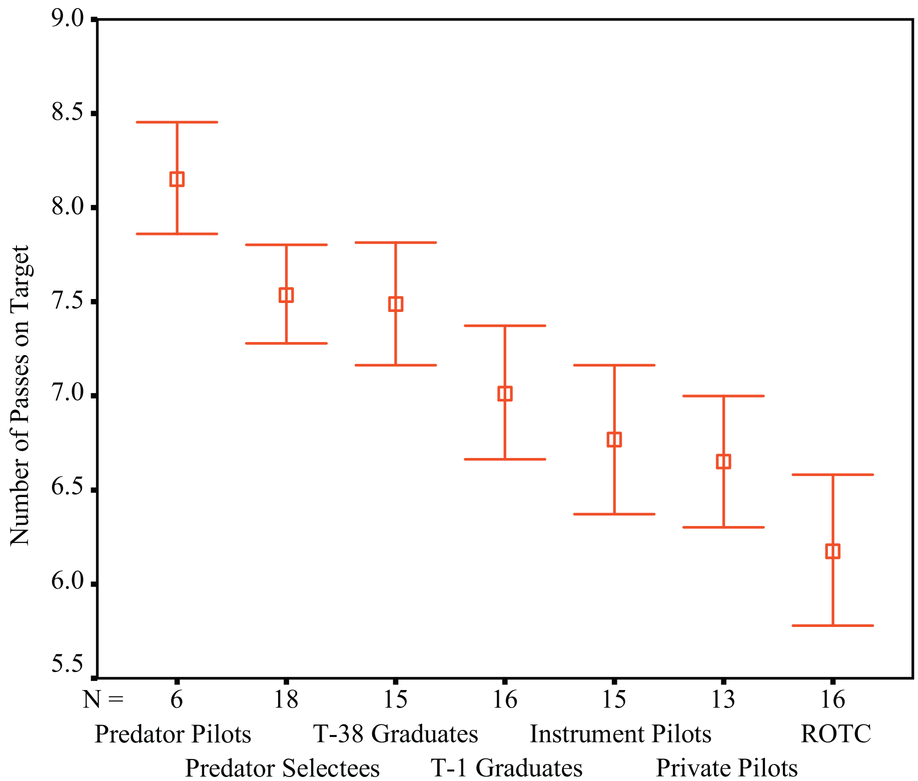

Figure 37. Mean number of passes through the target viewing area per scenario in the Reconnaissance task.

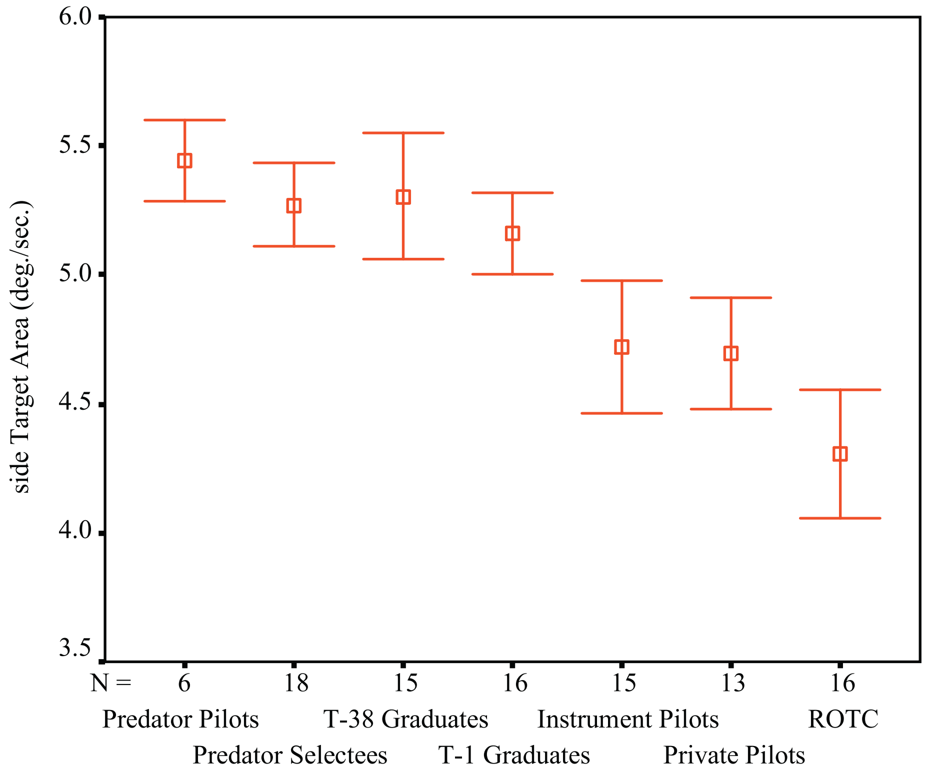

Figure 38. Average yaw rate per scenario outside of the target area in the Reconnaissance task.

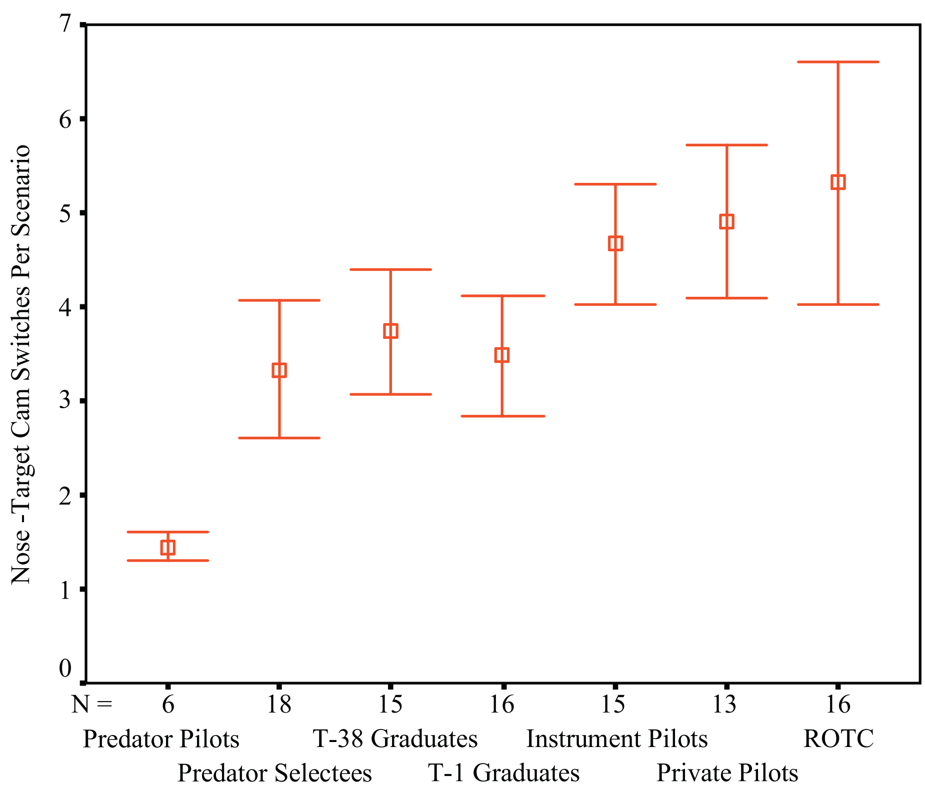

Figure 39. Number of switches between nose camera and target camera per scenario in the Reconnaissance task.

These results validate the initial task analysis. Unlike the Basic Maneuvering and Landing Tasks, the Reconnaissance Task is not primarily a test of the ability to control the aircraft within precise error tolerances. Instead, the task appears to require the ability to stay oriented without a constant forward-looking view, to keep in mind the relative positions of the aircraft, target, cloud hole, and target-viewable area are, and a feel for how to best position the aircraft to maximize target viewing time and minimize the time required to get back to some part of the target-viewable area after leaving it.

Demographic Data

The demographic questionnaire is presented in Appendix C. The overall result of analysis of participants' responses is that the demographic characteristics of the participants generally do not relate strongly to performance on our simulated Predator tasks. Significant relationships that do exist (e.g., between age and performance) are mediated by pilot group membership (e.g., ROTC students are younger and have no flight experience).

Part of the questionnaire concerned hobbies that have been informally mentioned as possible indicators of UAV pilot skill, namely frequency and type of videogame playing, and experience with remote-controlled hobby aircraft. Experience with nonflight-related, action-oriented computer games was not associated with better performance on our tasks. Neither was experience with remote-controlled toy aircraft. However, there was a small but statistically significant relationship between number of lifetime hours playing flight simulation computer games and landing performance. Those with more self-reported experience playing flight-related computer games needed fewer trials to pass the Landing Task criteria ($r = -.233$, $p = 0.022$). This relationship is not an artifact of age difference across groups. In fact, the relationship is strongest within particular groups, especially the T-38 and T-1 groups (T-38: $r = -.605$, $p = 0.017$; T-1: $r = -.582$, $p = 0.018$; Combined T-38 & T-1: $r = -.545$, $p = 0.002$).

These results do not prove that assigning randomly selected pilots to play computer flight games would necessarily make them better at flying the Predator. Other factors such as motivation to practice flying, or to excel at any flying-related challenge, could be mediating this relationship.

DISCUSSION

Reference Groups. It is clear that the tasks chosen and the underlying simulation were of sufficient fidelity, sensitivity, and validity to produce credible assessments of the ability to learn to fly the Predator. The Predator pilot reference group performed consistently better than all other groups in both overall measures of merit and detailed measures of technique. Conversely, the ROTC nonpilot reference group performed consistently worse, as expected. This latter result provides empirical support for the conclusions of the Hall and Tirre (1998) survey of Predator pilots regarding the necessity of some prior flying experience in piloting UAVs.

Candidate Groups. The groups of primary interest in this study were those that would be likely alternative candidates for selection to fly the Predator: current selectees, T-38 and T-1 graduates, civilian instrument pilots, and private pilots. On the major performance measures, especially the number of trials required to pass Basic Maneuvering and Landing Tasks, these groups did not differ dramatically. In particular, current selectees, T-38 graduates, and civilian instrument pilots showed nearly equal levels of performance on many measures. The high-level similarity of the performance of these groups was not due to experimental or measurement factors. For example, tasks were at the right level of difficulty to

avoid ceiling or floor effects. Differences between individuals within the groups were high, but enough data were gathered to allow the average performance of the different groups to be established with reasonable precision. Moreover, the pattern of overall group comparisons was replicated in many fine-grained supporting measures across different task segments. Therefore, the similarity in performance of several of the candidate groups is a solid and reliable finding. However, there is one major caveat. Even though the candidate groups did not differ much on many measures, some tasks and measures showed differences that are potentially important. We now discuss relevant specific considerations for each of the non-Predator pilot groups.

Predator Selectees

Perhaps the most striking finding from the Predator Selectee group is that they did not perform significantly better than some of the other, less experienced groups (e.g., T-38 graduates, civilian instrument pilots) on most measures. This reflects the fact that most of our tasks and performance measures tap Predator-specific handling skills. By the time a pilot has 150-200 flight hours, he or she has probably already developed most of the skills that are needed to prepare for learning basic maneuvers and landing in the Predator. Hundreds more hours, especially in non-Predator aircraft, may not give a pilot a substantial extra boost on basic handling tasks.

Another consideration in understanding the performance of this group is that the selectees are not necessarily a representative sample of all Air Force pilots with at least one operational weapons system tour. Moreover, while some of the selectees may have volunteered for Predator duty, others may not have been volunteers, which could affect morale and motivation not only for their upcoming assignment, but also for their participation in our tasks.

Finally, we reiterate that our study does not measure some less tangible but valuable characteristics of pilots. Officership, airmanship, communication skills, command experience, knowledge of combat operations, familiarity with airspace management, especially in war zones, and other skills gained from one or more operational tours may weigh in favor of using experienced pilots even if less experienced groups have the requisite basic piloting skills. In this regard, since the navigators currently selected for Predator have operational experience, it is unfortunate that a sufficient number of them were not available to form a separate comparison group.

Since selectees did not perform worse than other candidate groups, the Predator flying skill performance data reported here supports current selection practices and provides no compelling performance-based reason to change the current selection policy. Of course policy changes could easily be driven by cost or pilot availability issues, hence the inclusion of other groups in the study.

T-38 Graduates

T-38 graduates performed quite well on most of our measures. One explanation for their success at Basic Maneuvering and Landing is that, though there are certainly many differences, the T-38 aircraft has some important similarities to the Predator in handling characteristics and technique. Control by stick, sensitivity of the stick (i.e., responsive bank/pitch reaction by the aircraft), aggressive roundout/flare, shorter aimpoint at landing, and transition to landing with idle power are characteristic of both aircraft.

T-38 graduates also performed well on the Reconnaissance Task, which was presented after Basic Maneuvering and Landing training, and should be less sensitive to aircraft handling issues. Analysis of subsidiary performance measures on this task showed that T-38 pilots obtained extra time on target by maneuvering more aggressively than the civilian instrument and private pilot groups. They climbed to higher altitudes in the target area, cut airspeed more drastically when necessary, and made more aggressive turns outside the target area to return as quickly as possible.

T-38 pilots would be an acceptable candidate group for selection as Predator pilots if there were a way for them to obtain critical knowledge about combat operations equivalent to that achieved by a prior operational tour. The responsiveness of the T-38 to control surface manipulations appears to allow considerable transfer of skills to the Predator.

T-1 Graduates

On many of our measures, T-1 graduates performed less well than other groups with similar number of flight hours. Analysis of the detailed performance measures suggest that experience with the T-1 aircraft does not transfer as well to the Predator as does experience with T-38 or propeller aircraft. Unlike the T-38 and Cessna 172, the T-1 appears to have few readily identifiable similarities to the Predator. As a larger, yoke-controlled aircraft, the T-1 has more weight and inertia, thereby tending to dampen and delay the effect of control surface manipulation. Also the transition to land is more subdued than the aggressive roundout/flare performed by Predator pilots, T-38, and civilian Cessna 172 pilots. Another indication that the performance of T-1 pilots was affected by differences in aircraft handling is that, on the Reconnaissance Task, which is less dependent on precise aircraft handling, the T-1 graduates outperformed the civilian groups. (Another possible explanation for the slightly worse performance by the T-1 pilots relative to T-38 pilots on most of our tasks and measures is that the majority of the top ranked students from T-37 classes may choose and receive assignment to T-38 instead of T-1).

If prior operational experience were not required, T-1 graduates would be an acceptable choice from among the candidate groups for selection to fly Predator. However, based upon the performance data observed in this study, they would probably not be the first choice, possibly due to one of the speculative factors mentioned above. Nevertheless, since many successful Predator pilots originated from T-1s and other aircraft with handling characteristics different than the Predator, it is clear that these handling differences can be overcome.

Civilian Instrument Pilots

Civilian instrument pilots have almost the same amount of flying experience as T-38 and T-1 graduates, but of a different type. Although they have slightly fewer average number of flying hours than UPT graduates, they perform more actual aircraft landings during training (about 240 for civilians versus about 210 for UPT graduates). Though there are obviously many differences between civilian propeller planes and the Predator, there are some identifiable factors that may positively transfer to flying the Predator, such as relatively lightweight, propeller-driven dynamics, and aggressive transition to land with a short aimpoint.

This group, like the T-38 pilots, would be a suitable choice for Predator training if operational experience were not required. The flying skill demonstrated by the civilian instrument group would

support further investigation of a number of alternative Predator selection groups, including, but not limited to, new UAV-specific career/training paths for other non-UPT graduate Air Force officers, or the use of contractors. Since navigators currently selected for Predator pilot duty have at least as much light aircraft flight experience as the civilian instrument group in this study, the results from the civilian instrument group may also provide some support for the current practice of selecting navigators. However an important distinction is that all the pilots in the civilian instrument group had just completed their training, whereas navigators may have as much or more total flight experience, but less recent experience.

Civilian Private Pilots

Private pilots do fairly well on some of our landing measures, perhaps because private pilot training emphasizes repeated landings. They were the only group in our study with such frequent recent landing emphasis. However the Landing Task also demanded some instrument reference and calculation skills that presumably are developed to a greater extent in pilots with instrument ratings. This deficit also could underlie the private pilots' relatively poor performance on the Basic Maneuvering Task.

Private pilots would be the least suitable of any group we tested (except the nonpilot ROTC group) for selection as Predator pilots. Their lack of instrument flight experience is apparent in performance on our tasks.

ROTC Students

As mentioned previously, learning to fly a UAV may be problematic for some pilots because they cannot rely on some cues that are normally available in manned aircraft (e.g., vestibular cues, field of view, etc.). In this sense, the ROTC students may actually have had some limited advantage over pilots when first introduced to flying the Predator UAV simulation. However, the disadvantage of lack of flying experience outweighed any potential advantage. In all of the tasks, ROTC students performed worse than any other group. Despite declarative and procedural training and supplemental instructional documents, several participants in this group were unable to fully understand the complex relationship between bank, rudder, and crab angle in crosswind landing, some even after 200 landing trials and repeated voluntary reviewing of the crosswind instructional video. Also, many ROTC participants were not fully aware of the consequences of last-minute corrections on landings. They seemed to underestimate the magnitude and widespread ramifications of the corrections they made. Nevertheless, all ROTC participants were able to pass the crosswind Landing Task eventually. This often seemed to be the result of a very scripted effort to pass one step at a time within a landing trial, rather than understanding the complex interactions necessary to recover from any situation. Situations in which the aircraft's attitude or position was very far off of the "current step" often lead to overcontrol, frequently resulting in disastrous consequences. Therefore, they may have developed strategies for passing the task that would not generalize to comprehensive skill with a real aircraft.

The ROTC group was included in this study for two specific purposes. First the ROTC students are a referent nonpilot group to verify that the tasks reflect piloting skill. The data support this assertion, since ROTC students performed worse than pilots on both overall performance measures and detailed indications of aircraft control skill. These differences were found even though all groups were provided with declarative and procedural training.

Secondly, the performance of the ROTC group provides some relative indication of how long it might take to train a nonpilot up to a criterion skill proficiency level. Not surprisingly, based upon the flying skill demonstrated in this study, ROTC students are not a suitable candidate group for Predator UAV selection unless a specialized, lengthy Predator flight training program were to be initiated. They did, however, perform somewhat better than anticipated, especially on the Basic Maneuvering and Landing Tasks. Pilots from the T-38, T-1, and civilian instrument programs normally receive 200+ landings before graduation, yet the ROTC students were able to pass the Basic Maneuvering and Landing Tasks in about 161 attempts. This was probably not due to the task being easy; several of the experienced military pilots in this study reported the Landing Task as "the most difficult piloting task I've ever had to do." Rather, it may be that, while many aspects of pilot skill transfer to flying the Predator, other aspects may not. Experienced pilots may need to "unlearn" some aspects of piloting (e.g., use of vestibular and peripheral cues), whereas nonpilots who train only on the Predator would not.

CONCLUSION AND GENERAL RECOMMENDATIONS

The results of this study suggest that 150-200 hours of recent previous flying experience is sufficient, on average, to prepare a pilot to learn to fly a high-fidelity Predator simulation--if this experience is obtained in an aircraft with handling characteristics similar to those of the Predator. In particular, T-38 graduates and civilian instrument pilots performed nearly as well as current Predator selectees on difficult aircraft handling tasks in the simulator. This finding was to some degree unexpected, and it has possible implications for Air Force selection policy. Some general recommendations based on the results of the study are:

1. If prior operational experience remains a prerequisite for assignment to Predator, then the current practice of selecting experienced pilots should be continued. Current selectees performed at least as well as any other candidate group in this study, and better than some.

2. If critical knowledge about combat operations equivalent to a prior operational tour could be provided to candidate pilots, then, from a pure aircraft control skills perspective, either T-38 graduates or civilian instrument-trained pilots should be considered as a potential source of Predator pilots. However, in either instance, we would recommend that a test sample of at least 15 such pilots be trained in the Predator IQT and MQT programs, and the results evaluated, before any official change in policy is made.

3. Navigators with instrument ratings may be an especially attractive group to select from due to their operational experience, but we had insufficient data from them. We recommend that an additional 11 navigator selectees undergo our study protocol so that a complete picture of the capabilities of current selectees can be obtained. At present, our conclusions about the skill of current selectees only apply to those selectees with prior operational assignments as pilots.

4. We recommend that a cognitive task analysis of Predator combat operations be conducted with the goal of specifying the operational knowledge and skills that a Predator pilot must obtain, either from a prior tour or an apprenticeship program. This would include analysis of command and communications knowledge and skills, airspace management in war zones, and other specific knowledge about the conduct of combat operations.

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APPENDIX A: DESCRIPTION OF SYNTHETIC TASKS

The purpose of this section is to provide a description of some realistic unmanned/uninhabited aerial vehicle (UAV) pilot synthetic tasks developed by the Warfighter Training research Division of the Air Force Research Laboratory (AFRL/HEA). We recommend these tasks to researchers who wish to contribute to a body of knowledge about human performance issues in piloting UAVs. These tasks were built upon a detailed simulation of the Predator UAV developed by AFRL-Mesa via its on-site contractors and Parker International. This simulation is now being used to train all Air Force Predator pilots.

The design of these synthetic tasks results from a unique collaboration between experimental psychologists and expert pilots of the Air Force's Predator UAV. Tests using military and civilian pilots showed that experienced UAV pilots perform better on these tasks than pilots highly experienced in other aircraft, indicating that the tasks tap UAV-specific pilot skill.

Our aim in developing these synthetic tasks was to extract important segments of the UAV pilot's overall task—segments that tax the key skills required by a UAV pilot. We wanted to provide tasks that lend themselves to laboratory study, yet do not fall prey to oversimplifications that change the fundamental skills and strategies required to fly a real UAV. Our design philosophy and techniques are described in Martin, Lyon, and Schreiber (1998).

All of our UAV synthetic tasks use the same equipment. The equipment specifications are shown in Table 1. Figure 1 shows the experimental setup.

Table 1: Equipment List

Participant Station (runs synthetic tasks)	Dual 333 MHz Pentium II w/ 512K cache
	440 LX Motherboard P6DLS
	256 MB ECC SDRAM
	24x EIDE CD-ROM
	300 Watt Power Supply
	SoundBlaster 16 Sound card
	10/100 10BaseT Ethernet card
	1.44 MB Floppy drive
	Windows NT Workstation 4.0
	NT Service Pack 5
	Internal 100 MB Zip drive
	8.2 GB Maxtor EIDE disk Drive
	Two Elsa Gloria XL Graphic cards
	Two 16 MB Memory Upgrade for ELSA Gloria XL
	1 Additional fan kit
Researcher Station (tutorials, data storage)	Dual 200 MHz Pentium Processors
	128 MB ECC SDRAM
	SoundBlaster 16 Sound card
	10/100 10BaseT Ethernet card
	1.44 MB Floppy drive

	Windows NT Workstation 4.0 NT Service Pack 5 Standard Graphics card CD-ROM 8.2 GB Maxtor EIDE disk Drive 1.44 MB Floppy drive Internal 100 MB Zip drive 1 Additional fan kit
Additional Hardware	Two 25' 10BaseT Ethernet Cables One 100 MHz Ethernet Hub Three 110V AC Surge Three 17" CRT Monitors (CTX VL-710, 0.25mm) Joystick (Thrustmaster PFCS serial) Rudder (Thrustmaster Elite Rudder Pedals) Throttle (Thrustmaster WCS)

The apparatus consists of a flight control stick at the right hand, a throttle at the left hand, rudders (not shown), a keyboard, and two adjacent 19" color monitors. During each task, the left-hand monitor displays the Predator UAV primary flight control instrumentation, sometimes superimposed over simulated video from the sensor camera. The right-hand monitor often contains a map display but can show other information depending on the task. (The computer on the right is the experiment control station, which is normally outside the pilot's view on another table.)

All of the tasks have a common general structure. The pilot first works through a computer-based multimedia tutorial that provides information necessary to interpret the displays and perform the tasks. When he or she is ready to begin the task, an initial display screen shows information about the trial that is about to begin. When the pilot is ready, he or she presses the trigger on the control stick and the trial begins. After the trial finishes, a feedback screen is presented showing the results of detailed performance measures.

We will describe three synthetic tasks—the Basic Maneuvering Task in which a pilot must make controlled changes in UAV airspeed, altitude, and heading; the Landing Task in which the UAV must be guided through a standard approach and landing; and the Reconnaissance Task in which the goal is to obtain simulated video of a target through a small break in cloud cover.

Basic Maneuvering Task

The Basic Maneuvering Task was designed to train people with various types and amounts of flying experience up to a standard level of basic Predator UAV flying proficiency. After achieving this proficiency standard, more specific Predator UAV piloting skills can be tested with other synthetic tasks. The structure of the Basic Maneuvering Task was adapted from a task designed at the University of Illinois to examine scan patterns of pilots who differed in experience flying a small aircraft (Wickens, Bellenkes, & Kramer, 1995). However the current task uses Predator UAV instrument displays and includes extensive performance measurement and feedback information.

The Basic Maneuvering Task is a set of timed basic flying maneuvers. The task requires the participant

Figure 1. Predator Synthetic Task Environment equipment setup.

to fly seven distinct maneuvers while maintaining acceptable root-mean-squar (RMS) error limits on the parameters of altitude, airspeed, and heading. Each maneuver starts with a 10-second straight-and-level, lead-in section as the participant prepares to execute the maneuver. At the end of this lead-in, the timed maneuver segment (either 60 or 90 seconds) begins and the participant is required to maneuver the aircraft at a constant rate of change with regard to each of the three parameters. The initial segments require the participant to perform maneuvers that change in one parameter while holding the other two constant. For example, the participant may be required to reduce airspeed while maintaining altitude and heading. The maneuvers increase in complexity by requiring the participant to fly maneuvers that change in combinations of two parameters. The final maneuver requires changing all three parameters simultaneously. The participant is not allowed to continue on to the next maneuver until the RMS criterion error limits have been achieved on all three parameters for the current maneuver. These limits were chosen after the tasks were flown by highly experienced Predator pilots. The idea was to set performance goals that could be achieved by a skilled Predator pilot after a few familiarization trials. These limits are easy for a programmer to modify if desired.

Figures 2 and 3 show the displays that appear while someone is performing the Basic Maneuvering Task. The left monitor depicts the Predator flight information overlaid on a pure black background, requiring the participant to fly the tasks by instruments only (Figure 2). The pertinent flight information is altitude, digital heading, vertical speed indicator, artificial horizon, heading rate indicator, and engine revolutions per minute. The right monitor displays other useful information, such as a moving compass, a bank angle indicator, the time remaining in the maneuver, and the start/end parameter values for the maneuver currently being flown (Figure 3). At the end of the maneuver, the right monitor displays feedback to the participant (Figure 4).

Both the optimal and the actual parameter values over time are graphed for each of the three parameters, with time on the abscissa and the value of the parameter on the ordinate. The average RMS error for each parameter is also shown. If a participant failed any parameter on that maneuver, the corresponding RMS error value will flash on and off. Once the participant passes all seven Basic Maneuvering Task segments, he/she moves on to the Landing Tutorial and the Landing Task.

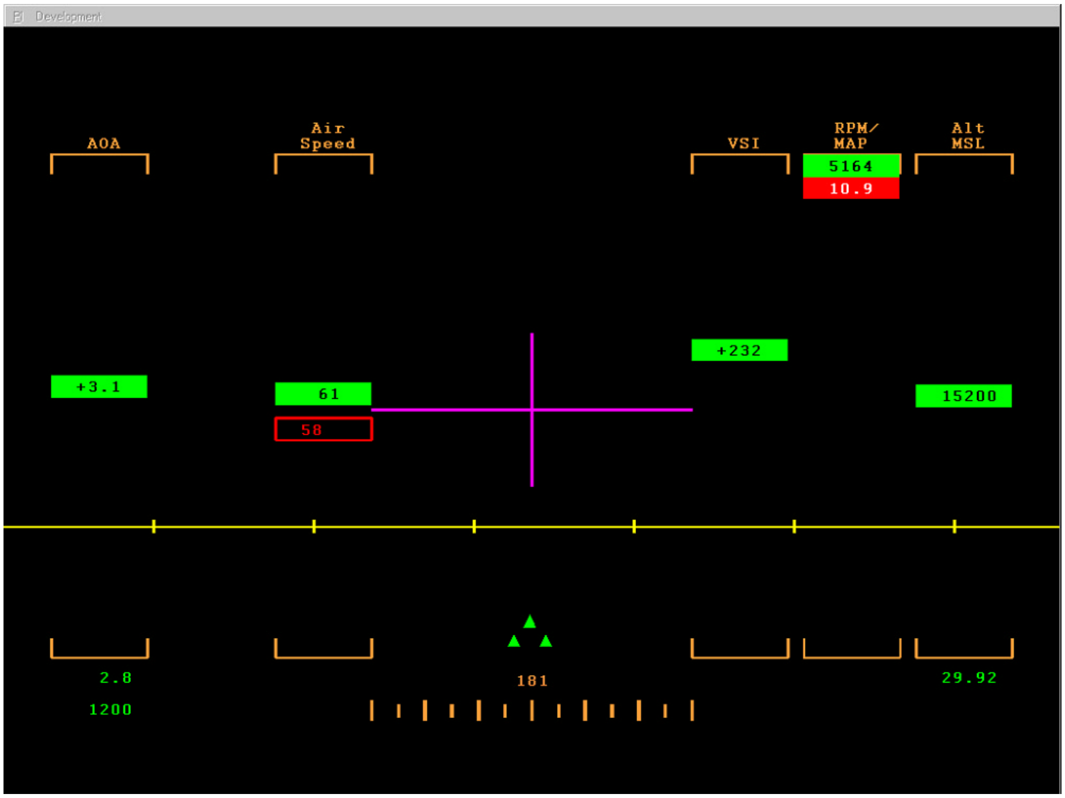

Figure 2. Predator "Heads-Up Display" overlaid on black background.

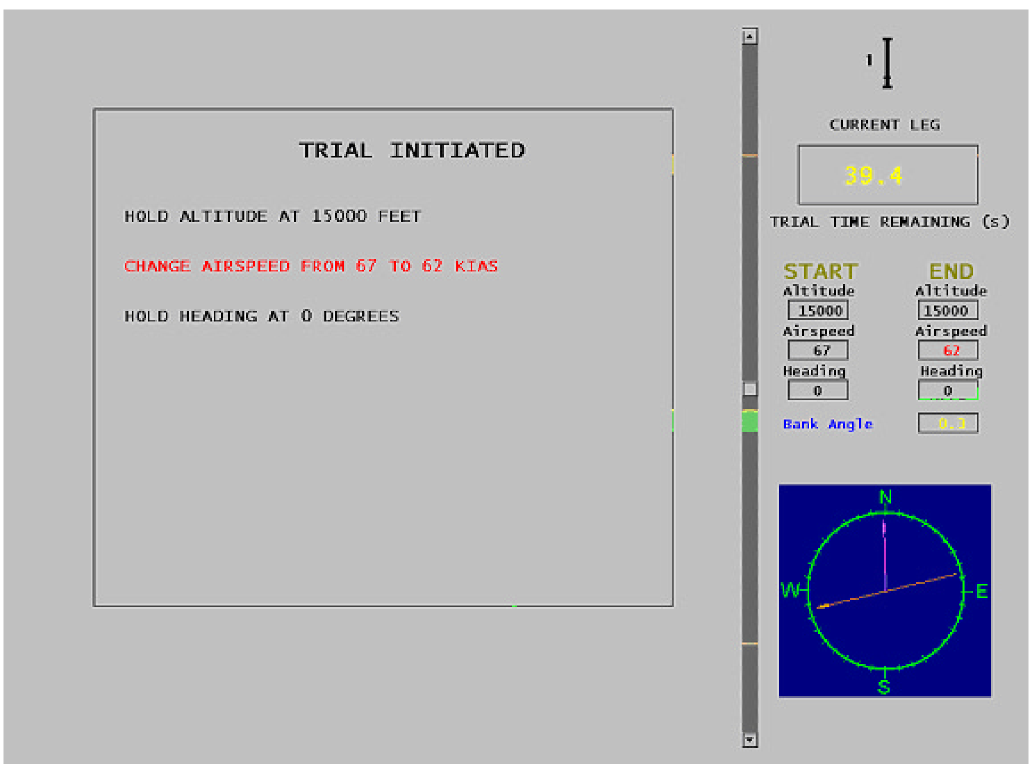

Figure 3. An example of what is displayed on the right-hand monitor during the Basic Maneuvering Task. In this particular instance, the maneuver is to reduce airspeed while holding altitude and heading constant.

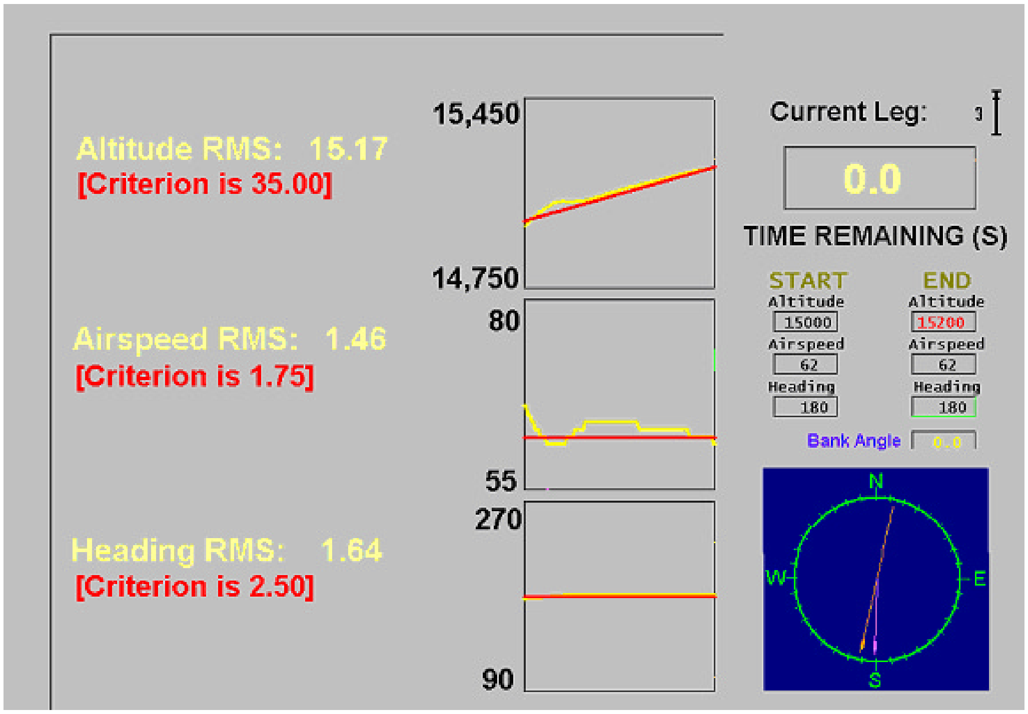

Figure 4. An example of the feedback for the Basic Maneuvering Task. Criterion performance levels shown in brackets, while the participant's performance is graphed and displayed in yellow. In this particular example the maneuver asked for increasing altitude only while holding airspeed and heading constant.

Landing Task

Perhaps the most difficult task associated with the Predator UAV is landing. In addition to flying with a line-of-sight control delay, remotely controlling the aircraft on landings leaves the pilot with no vestibular cues to feel the flare and sinking feelings, and no peripheral visual cues to notice the surrounding terrain rising in the last few moments before touchdown. These factors complicate the pilot's task of controlling a slow-moving aircraft with a long wingspan that is naturally susceptible to crosswinds and other disturbances. Our Landing Task—our most difficult synthetic task—replicates most of the difficulties encountered by an operator of the actual Predator UAV during an approach and landing (except that turbulence and ground effects are not simulated). It requires the pilot to exceed criterion level of performance on 13 different parameters on the same landing attempt, first for a no-wind landing and then a cross-wind landing.

The participant is asked to fly the approach pattern, maintain glideslope, and safely land the aircraft. At the start of each landing attempt, the participant's plane is initialized at 800 feet with the gear down on the downwind leg of one of the landing patterns Predator pilots used at Indian Springs Air Force Auxiliary Field (AFAF) (Figure 5). The Predator flight displays are overlaid on the simulated 30-degree nose camera imagery and displayed to the participant on the left monitor (Figure 6).
The 13 parameters that must be met are: RMS pattern groundtrack error, altitude at three different points in the pattern, RMS final approach groundtrack error, RMS final approach glideslope error, touchdown bank angle, touchdown pitch angle, touchdown groundspeed, touchdown instantaneous sink rate, touchdown heading relative to runway, touchdown distance off centerline, and lateral movement at touchdown (measure of side-loading). Feedback on all these parameters is shown on the right-hand monitor at the conclusion of the landing attempt (Figure 7).

As was the case for the Basic Maneuvering Task, if the participant fails one or more parameters, the task is flown again until criterion performance is attained on all parameters on the same landing attempt. Once the participant has passed a no-wind landing attempt, then passes one of the cross-wind landing conditions (of four), he/she moves on to the Reconnaissance Tutorial and the Reconnaissance Task.

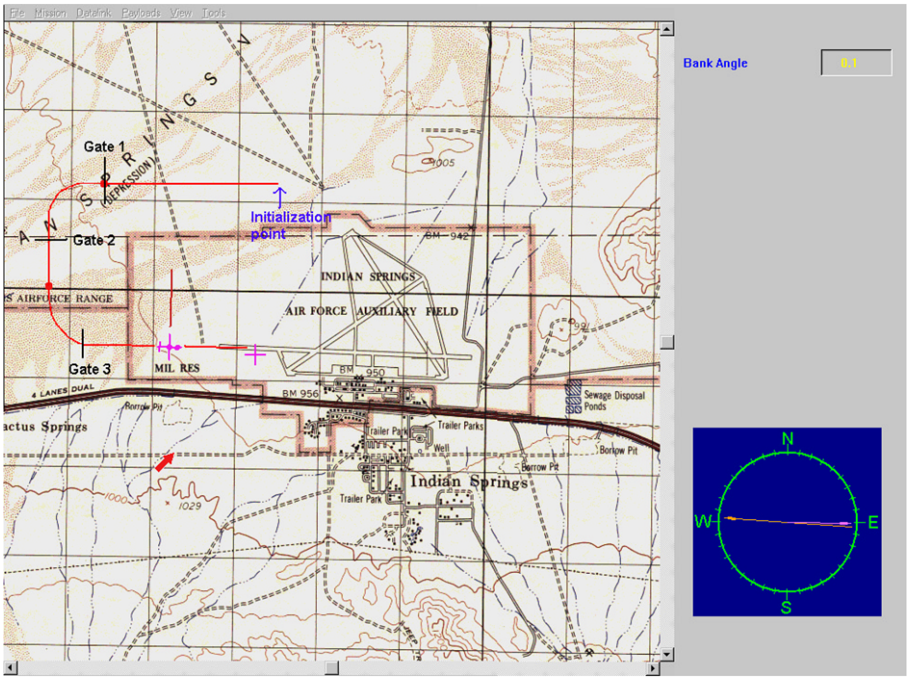

Figure 5. The tracker map is displayed on the right-hand monitor. This example shows a plane on final approach. The participant sees only the map and plane icon; we have superimposed the approach path (red line), turn points (red dots) and altitude gate positions (black lines) for illustrative purposes only.

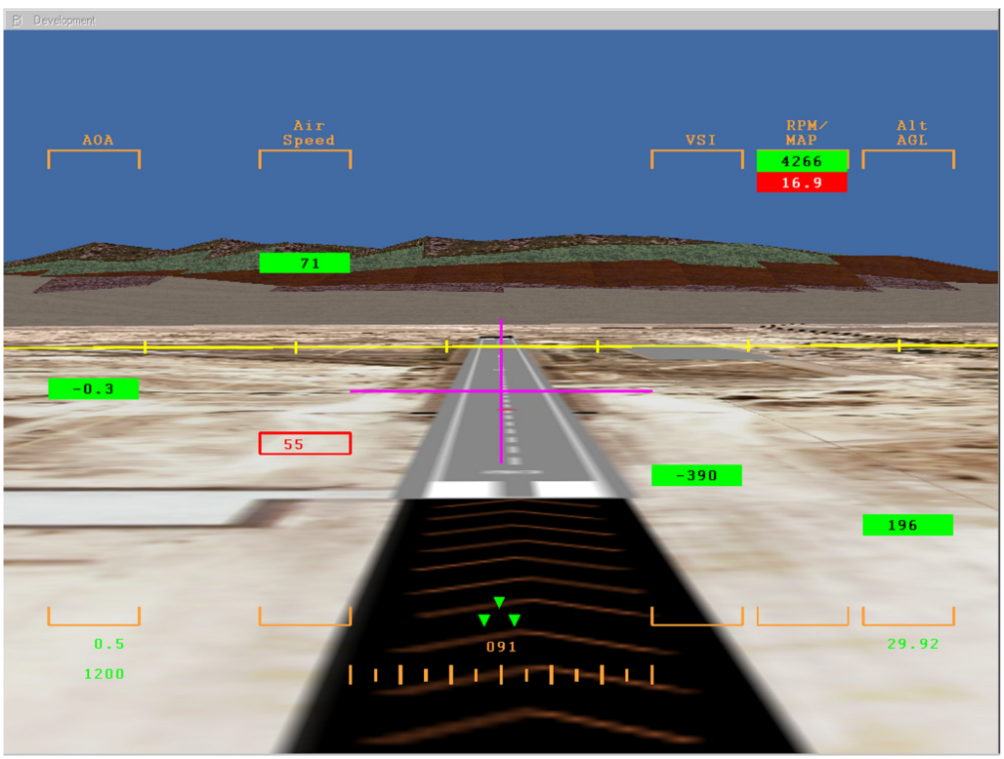

Figure 6. The forward-looking nose camera view with Predator displays. Shown here is the aircraft on final approach.

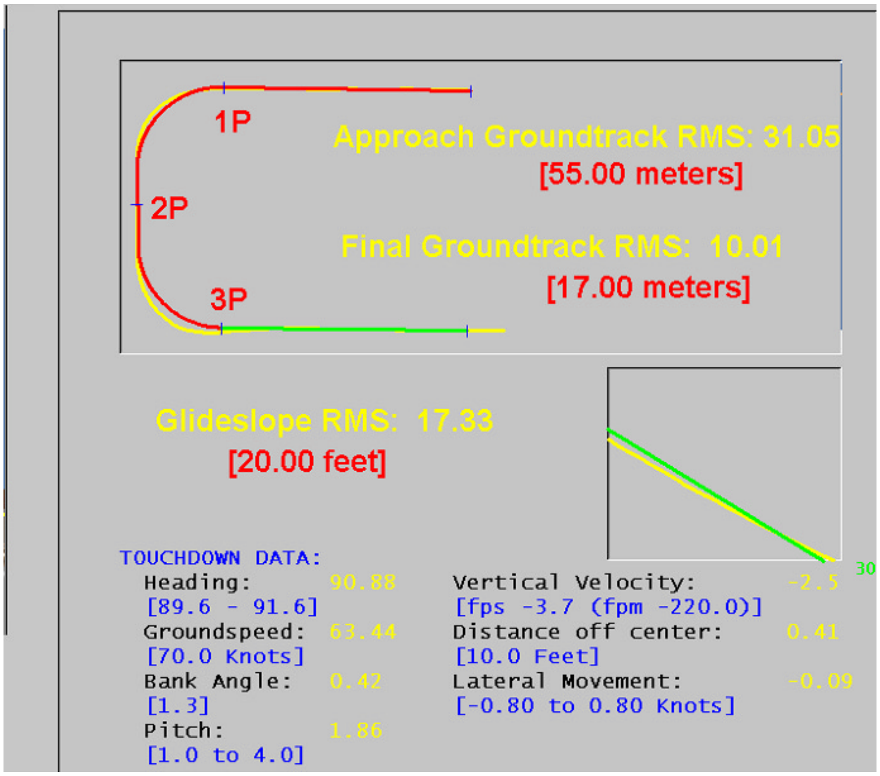

Figure 7. Feedback for each of the 13 Landing Task parameters. Criterion performance levels shown in brackets, while the participant's performance is graphed and displayed in yellow.

Reconnaissance Task

One frequent and difficult aspect of an operational reconnaissance mission is getting electro-optical (EO) imagery of a target through holes in clouds. The skill of the pilot is particularly important in this situation, since he/she must maneuver the UAV such that the UAV, the target, and a cloud break are all aligned (Figure 8) in order to obtain time on target (TOT) with the EO camera. A few factors adding to the difficulty of this task are the unpredictable location of the cloud break, the effects of wind on the UAV, no-fly zones, altitude and time restrictions, threat rings, terrain, and the maneuverability constraints of the Predator itself.

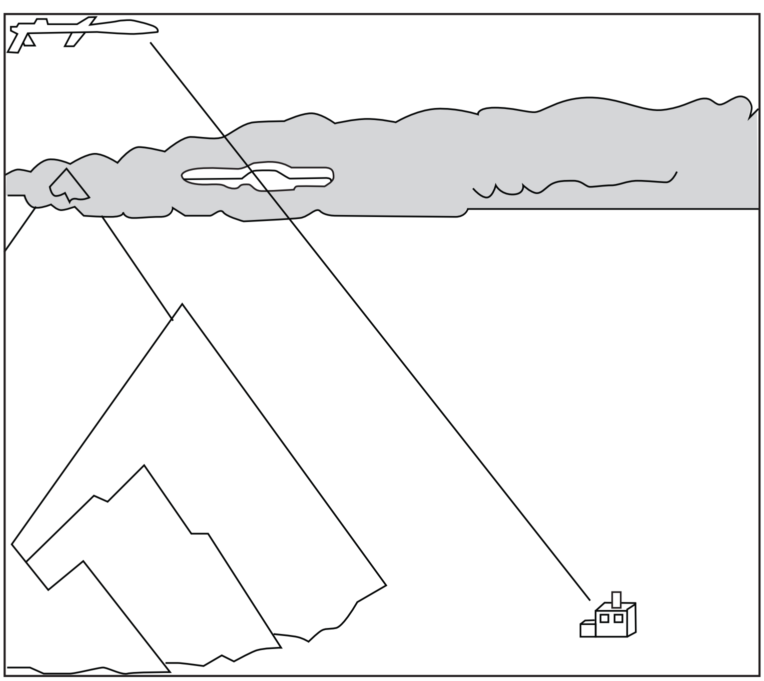

Figure 8. Schematic drawing of the Reconnaissance Task.

In our synthetic Reconnaissance Task, the participant encounters these same difficulties. The Reconnaissance Task consists of 10-minute missions (trials) in which the participant must maximize time on target (TOT) while taking into account various constraints and hazards in his/her attempt to align the Predator, the cloud-break, and the target. Time spent in violation of altitude, airspeed, or no-fly zones results in penalty time, which is subtracted from accumulated TOT. In addition, the participant is instructed to avoid situations that would ordinarily make it difficult (in the real Predator team setting) for the camera operator to obtain quality EO imagery. Therefore TOT is not accumulated if the participant flies directly over the target (within 88-90 degrees) or banks the aircraft more than 5 degrees while the camera is on target.

At the beginning of each mission, the participant is initialized at the southern edge of the tracker map at 12,000 feet heading north towards the target. The entire area is cloud-covered, except for a single break in the clouds somewhere nearby. Several resources are available to the participant. In addition to the Heads-Up Display (Figure 9) and the tracker map (Figure 10), the participant has a choice of camera

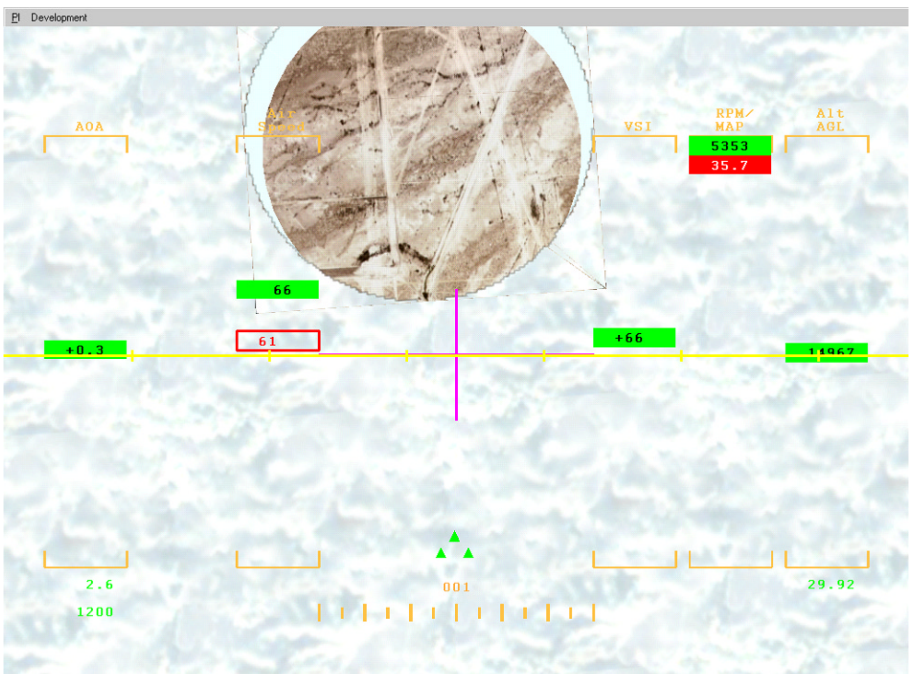

Figure 9. Heads-Up Display overlaid on target camera view. In this illustration, the target (a point on a runway) is almost in view. While in the target camera view, The reticle (purple cross-hair) is always pointed at the target on the ground. However, as illustrated in this example, clouds often obscure the target.

views. In the actual Predator, satellite transmission is required and only allows enough bandwidth for one video feed. Therefore in our synthetic task the participant must choose to use either the EO camera or the nose camera. The participant has the ability to switch between cameras at any time; however, the EO camera must be in use to obtain TOT, while the nose camera should be used only to aid orientation.

The primary measures of performance for each trial of this task are: total time-on-target, duration and frequency of target-viewing episodes, and duration and frequency of each constraint violation. In addition, after completion of each trial, the participant is asked to place a cursor (the red arrow in Figure 10) where he or she believes the center of the cloud hole to be located. Distance and direction and response time of this cursor placement from the veridical cloud hole location are recorded. The feedback screen shows digital values for the total time on target, time in penalty, hole estimation error distance, number of bank angle and depression angle infringements, and number of altitude, airspeed, and no-fly

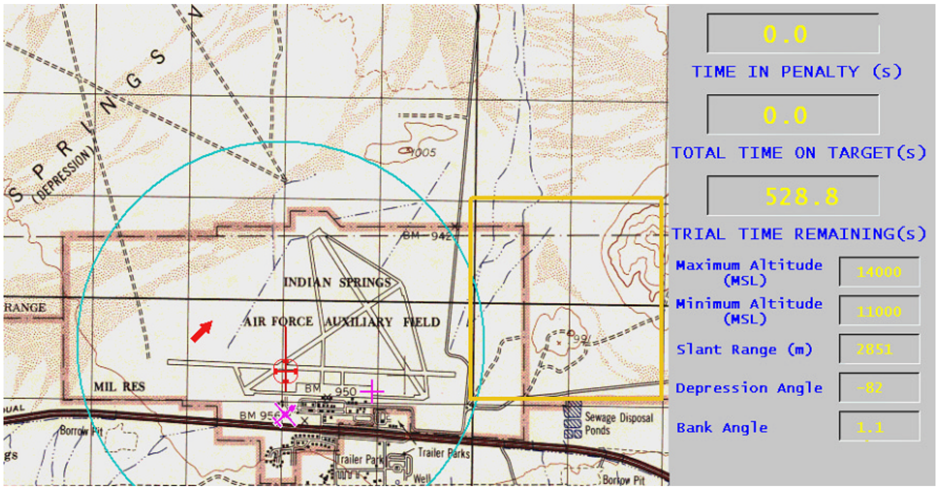

Figure 10. The tracker map. The target is depicted in red by the red plus symbol outlined by the red circle. The large yellow box represents a no-fly zone, while the large blue circle outlines the area in which the cloud hole is located. Time on target, penalty time, time remaining, altitude constraints, slant range, depression angle, and bank angle are all shown to the participant in the gray status area.

zone violations. The synthetic task software also includes a program that displays to the researcher the path flown by the participant superimposed on the tracker map and color-coded to reflect key events such as time on target or constraint violations.

Summary

These three synthetic tasks, taken together, provide a way to measure and study some of the most critical skills required to pilot a Predator-like UAV. The complete software necessary to run these tasks, including data logging and performance measurement is available to Air Force Office of Scientific Research (AFOSR)-supported university or government laboratories upon request. For more information, or to request the software, contact Dr. Elizabeth Martin, AFRL/HEA, at 480-988-6561 (elizabeth.martin@williams.af.mil)

APPENDIX B: SOFTWARE DESCRIPTION

Software Architecture

The unmanned/uninhabited aerial vehicle (UAV) Simulation Environment (USE) is a multiple-computer system that communicates over a 100 MHz Ethernet backbone. The USE software is modular—it consists of nine separate programs, written in C, each executing individually. Although these programs are running separately, they are continually communicating with one another through sockets. These sockets, essentially ports within each program, send and receive data over the network.

The main program coordinating much of the communication is called use_os. This program must be running on each PC for the software to operate. Use_os is the administrator for the USE system and coordinates timing and keyboard inputs.

Each program represents a different piece of functionality for the system:

1.	USE_OS	Overall administrator
2.	USE_HFUAV	UAV aerodynamics / vehicle response
3.	USE_SCSC	Menu system / ground control station functionality
4.	USE_HFHCI	High-fidelity controls
5.	USE_LFHCI	Low-fidelity controls (runs on researcher computer)
6.	USE_TM_HCI	Low-fidelity controls (runs on participant computer)
7.	USE_PI	3D graphics window
8.	USE_TRACKER	Map display
9.	USE_IOS	Research interface / instructor operator interface

The system is designed to reproduce in software the actual flow of information in the real system. The two core software modules, use_hfuav and use_scsc, are the main pieces of the Predator simulation. The use_scsc program replicates the ground control station (GCS) from the actual Predator system. The outward interface for this program is the menu system used in the GCS. It will not only take the menu commands and act upon them, it accepts data from other processes, aggregates it into a data structure called TIV, and transmits to the process representing the Predator UAV. The use_hfuav (hfuav stands for high- fidelity uav) represents the actual aircraft in the system and receives commands and information from use_scsc. The software reacts to the commands and inputs, and reports the results, in a structure called VIT, back to the other processes. For example, if the user makes a stick input, the software reading the stick sends the information to use_scsc where it is packaged in the TIV. This information is then sent to use_hfuav and is used, along with other state information, to determine the aircraft's response and new state. The results are then packaged in the VIT and broadcast over the net.

Software Listing

Folders and functionality: Each number is a folder in the USE directory. The files in each directory follow along with a brief description.

1.	Configuration: contains various configuration files.
Aero.txt:	allows modification of aerodynamic parameters. Only adjust if you know what you are doing. Explanations are given.
Default_dialog_color.txt:	changes color of dialogs presented for trainer. Most of these dialogs appear

	when using the pull-down menus on the Tracker map.
Fov.txt:	changes field-of-view and other sensor settings.
Hci_deadband.txt:	changes stick deadband.
Hci_hybrid.txt:	specifies control configuration (i.e., research or high fidelity). Explanation given in file.
Left_emp.txt:	specifies emergency mission plan waypoints for left rack.
Left_hfhci.txt:	file containing calibration data for stick (left rack). This file is generated through the menu system's calibration area.
Left_omp.txt:	specifies operational mission plan waypoints for left rack.
Magvar.txt:	specifies magnetic variation.
Pi.txt:	log for database files loaded at startup.
Powerup_config.txt:	log for scenario file loaded at startup.
Right_emp.txt:	specifies emergency mission plan waypoints for right rack.
Right _hfhci.txt:	file containing calibration data for stick (right rack).
Right _omp.txt:	specifies operational mission plan waypoints for right rack.
Uav_aero_coefficients.txt:	specific aircraft characteristics for flying (e.g., roll limit). Changing these will have less serious affects than aero.txt parameters. These are more related to the stability augmentation control system in the Predator and will be used mostly to limit flight performance.

2. Data: contains maps for the Predator ground control station. You should store your maps here for consistency. The *.ga is a format used by the contractor who manufacturers the Predator. Other maps generated through the National Imagery and Mapping Agency's (NIMA) tools (e.g. files with *.adr or *.cab) will work. You will need arc digitized raster graphic (ADRG) or compressed arc digitized raster graphic (CADRG) data, and will use the NIMA software to cut out the desired areas. Check out www.nima.mil for information and the software to generate your own.

3. Databases: contains data for Distributed Interactive Simulation (DIS), databases and mission/research scenarios.

Dis:	contains DIS configuration files. Not necessary for research.
Zhunter_liggett:	Hunter Liggett database (original). Not used.
Zindian_springs:	Indian Springs database (original). Used for Air Force Research Laboratory (AFRL) research tasks. This area contains the digital terrain elevation data (DTED) for the 3D database, the initial ADRG maps loaded at startup, and the database's textures. The NIMA software generates both the DTED and the ADRG maps. Using the software and data CDs, you cut out the area desired and place it in this file.
Zscenarios:	scenario files for tasks and training scenarios. Scenarios are for AFRL research tasks. These are in folders labeled Basic_Maneuvering_Task_Leg_x, Cloud_Break_Trial_Number_x, and Landing_task_trial_number_x. The (x) denotes trial number. The files in each of these folders is self-explanatory and handles some portion of the initialization for the task. The other folders contain canned scenarios used in the trainer (they specify starting conditions)

4. Executables: contains system executables, custom *.dlls, icons and *.cmd (boot commands) files for automation. The command files will execute the programs needed for the function specified in their title. The two most important files are use_boot_scsc and use_boot_pso. These are the two necessary to start the research software. Use_boot_scsc.cmd will spawn use_scsc.exe. It will also execute use_lfhci.exe, and use_ios.exe, which are necessary for complete functionality on the menu computer. It may also spawn, over the network, use_boot_pso.cmd. This will then spawn the processes necessary for the pilot rack. These are use_hfuav.exe, use_ios.exe, use_tm_hci.exe, use_pi.exe, and use_tracker.exe. It is possible to edit these boot command files to add/delete programs started. Simply right click on the files, select edit, and change them according to the format shown.

5. Help: contains help files that appear when you ask for help through the trainer software.

6. ITAR_and_Proprietary: contains copyright and International Traffic in Arms Regulation (ITAR) messages regarding redistribution.

7. Logistics Support: contains update command files (*.cmd) to assist in updating stations), and runway pictures verifying runway alignment.

8. Missions: contains various mission plans generated through the mission plan functionality of the USE software.

9. Presets: contains presets files for the software. These are generated through the Presets area of the pulldown menus.

10. Projects: source code for divisions of the USE software.

Use_api:	contains the header and library files for the USE software. You will make no changes in this file. This contains the main data structures for the software. The other processes expect this data in the format. Of importance is the use_api.h file. This file contains the main data structures used in each process. Specifically, it contains the VIT and TIV structures that communicate the aircraft state information across the net.
Use_dis:	contains software for the USE implementation of the DIS protocol. This is not fully functional.
Use_hfhci:	software to read inputs from the high-fidelity controls on the actual trainer. This is not used in the current research configuration.
Use_ios:	research software. This is where all the tasks are programmed. This project spawns the process that is the interface for the research.
Use_lfhci:	software to read the inputs from the low-fidelity controls on the research station. This runs on the instructor operator station (IOS) computer and translates the low-fidelity control inputs into compatible format (the hfhci format).
Use_pi:	3D database and visuals generation software. This is the rest of the rendering software. Originally, access was only granted through the plug-in. Using these two modules, one has access to all the rendering source code.
Use_pi_pi:	3D database and visuals generation software. This is a plug-in for the rendering software and does not control everything.
Use_tm_hci:	second software module to read the input from the low-fidelity controls.

	This must run on the pilot's / subject's station. It will take the inputs and send them to use_lfhci.
Use_tracker:	tracker map software. This is the rest of the map software. Originally, access was only granted through the plug-in. Using these two modules, one has access to all the map source code.
Use_tracker_pi:	tracker map software. This is a plug-in for tracker map software and does not control everything.

Software Modifiability

The types of modifications that can be accomplished are external to the Predator-specific simulation. The two core software packages, use_hfuav and use_scsc, are inaccessible. The programmer is unable to access this functionality and modify it. The implications of this are that researchers are unable to modify the predator-specific personality of the aerodynamics and aircraft response. An example is that it is impossible to modify menu commands or their interactions with the use_hfuav process.

The basic system architecture allows a programmer to tap into the data being transmitted on the different sockets and use it for custom applications. This translates into being able to create a new program that traps the data and performs some action desired by the user. For example, one can program a map display and position the aircraft based upon the data received. The update rate of this data is 20 ms and it is controlled by a heartbeat from the use_os application.

With the exception of the two core processes, it is possible to replace some of the existing applications with new ones. An application is transparent to the others as long as it transmits any data the others require. For example, a custom 3D view can be inserted using the data from the core processes. It should be mentioned that these peripheral processes do receive data from the core applications and functionality could be implemented to act upon them. Some examples are the reactions the 3D view has to menu commands from the SCSC process. A less invasive possibility is to modify one of the plug-in or parent modules. The plug-ins, legacy from an older design, allow access to some of the functionality, like the HUD. The parent applications use the plug-ins and their own code to generate the complete program. This methodology is used in the map and 3D graphics applications. Using these it is possible for the programmer to modify the HUD, Terrain or Map display for a customized application. Just to reiterate the limitations, the effects of the tracker map pull-down menus are not modifiable because they rely upon the SCSC module.

Processes	
Hfuav	- use_hfuav.exe
3D graphics	- use_pi.exe
Menu	- use_scsc.exe
High-fidelity controls	- use_hfhci.exe
Low-fidelity controls (menu)	- use_lfhci.exe
Low-fidelity controls (3D graphics)	- use_tm_hci.exe
Map	- use_tracker.exe
Instructor operator station	- use_ios.exe

Socket Listing:

7777 Left Operator Keyboard Input: transports from 3D graphics computer to menu computer
7778 Right Operator Keyboard Input: transports from 3D graphics computer to menu computer
8779 Left Operator Menu Bar commands: transports from 3D graphics process to menu process
8780 Left Operator menu commands: transports from menu process to 3D graphics process
8781 Right Operator Menu Bar commands: transports from 3D graphics process to menu process
8782 Right Operator menu commands: transports from menu process to 3D graphics process
8783 Left Operator map presets: transports from map process to menu process
8784 Right Operator map presets: transports from map process to menu process
8785 Left Operator GCS data (TIV): transports from menu process to map process
8786 Right Operator GCS data (TIV): transports from menu process to map process
8787 Left Operator vehicle data (VIT): transports from hfuav process to map process
8788 Right Operator vehicle data (VIT): transports from hfuav process to map process
8790 High/Low-fidelity control data (analog and digital inputs): transports from high/low-fidelity controls process to menu process
8791 High/Low-fidelity control data: receive port for digital outputs
8792 Left Operator vehicle data (VIT): transports from hfuav process to 3D graphics process
8793 Right Operator vehicle data (VIT): transports from hfuav process to 3D graphics process
8794 Left Operator GCS data (TIV): transports from menu process to 3D graphics process
8795 Right Operator GCS data (TIV): transports from menu process to 3D graphics process
8796 Left Operator GCS data (TIV): transports from menu process to instructor operator station process
8797 Right Operator GCS data (TIV): transports from menu process to instructor operator station process
8798 Left Operator vehicle data (VIT): transports from hfuav process to instructor operator station process
8799 Right Operator vehicle data (VIT): transports from hfuav process to instructor operator station process
8800 Left operator receive port for digital outputs: transports from low-fidelity controls process on 3D graphics computer to low-fidelity controls process on menu computer
8801 Right operator receive port for digital outputs: transports from low-fidelity controls process on 3D graphics computer to low-fidelity controls process on menu computer
8802 Left operator low fidelity control data: transports from low-fidelity controls process on 3D graphics computer to instructor operator station process
8803 Right operator low fidelity control data: transports from low-fidelity controls process on 3D graphics computer to instructor operator station process
8879 Left Operator vehicle data (VIT): transports from hfuav process to menu process
8880 Left Operator GCS data (TIV): transports from menu process to hfuav process
8881 Right Operator vehicle data (VIT): transports from hfuav process to menu process
8882 Right Operator GCS data (TIV): transports from menu process to hfuav process
8884 Instructor operator station commands: transports from instructor operator station process to 3D graphics process
8885 Instructor operator station commands: transports from instructor operator station process to map process
8886 Instructor operator station commands: transports from instructor operator station process to hfuav process

8887 Instructor operator station commands: transports from instructor operator station process to high-fidelity controls process
8888 Instructor operator station commands: transports from instructor operator station process to menu process
8892 Remote Spawn Commands
8898 Raw high-fidelity control data (analog and digital inputs): transports from high-fidelity controls process to instructor operator station process
8998 High/Low-fidelity control data (analog and digital inputs): transmit from high/low-fidelity controls process to instructor operator station process

Data Analysis Software

A data analysis software package has been developed to facilitate results visualization and data extraction. Written in C++, this software uses classes to ease data extraction. A class has been developed for each task (Basic Maneuvering, Landing, and Cloud Break) that contains the functions and data structures to easily access trial data. All source code is available.

Output of Summary Data Files

The synthetic tasks contain built-in performance measurement and data capture. Each trial produces a large trial data file. Selected variables from the trial files are aggregated into a summary file, which contains one line of data per subject per trial. The following tables show the variables that are included in these summary files for each of the three tasks.

Basic Maneuvering Task Summary File

cbp->research_subject_number	Participant number
cbp->research_trial_number	Participant trial
cbp->research_session_number	Participant session
cbp->research_scenario_number	Participant scenario
iFail_pass_trial_BM	Pass fail flag for trial
fAltitude_rms_error	Altitude RMS error
fHeading_rms_error	Heading RMS error
fAirspeed_rms_error	Airspeed RMS error
roll_trim_success	Number of successful trims in roll
roll_trim_failure	Number of failed trims in roll
pitch_trim_success	Number of successful trims in pitch
pitch_trim_failure	Number of failed trims in pitch
fResearch_bm_start_elev	Start altitude
fResearch_bm_start_head	Start heading
fResearch_bm_start_speed	Start speed
fResearch_bm_start_head	Start heading
fResearch_bm_end_elev	End altitude
fResearch_bm_end_head	End heading
fResearch_bm_end_speed	End speed
fResearch_bm_trial_duration_seconds	Trial duration in seconds

Landing Task Summary File

cbp->research_subject_number	Participant number
cbp->research_trial_number	Participant trial
cbp->research_session_number	Participant session
cbp->research_scenario_number	Participant scenario
iPass_fail_flag	Trial Pass/Fail flag
dTouchdown_heading	Heading at touchdown
dTouchdown_groundspeed	Groundspeed at touchdown
dTouchdown_vsi	VSI at touchdown
dTouchdown_uav_x	Uav x position at touchdown
dTouchdown_uav_y	Uav y position at touchdown
dTouchdown_uav_z	Uav z position at touchdown
dTouchdown_uav_bank_angle	Uav bank angle at touchdown
dTouchdown_uav_lateral_movement	Uav lateral movement at touchdown
dTouchdown_pitch	Uav pitch at touchdown
iAltitude_test[1]	Results of altitude test at gate 1 (0 = fail, 1 = pass)
iAltitude_test[2]	Results of altitude test at gate 2 (0 = fail, 1 = pass)
iAltitude_test[3]	Results of altitude test at gate 3 (0 = fail, 1 = pass)
dGroundtrack_approach_rms_error_LT	Approach groundtrack RMS error
dGroundtrack_final_rms_error_LT	Final groundtrack RMS error
dAltitude_rms_error_LT	Altitude RMS error on final
doTotal_trial_time_seconds	Trial time in seconds
doApproach_time	Time in Approach
doFinal_time	Time in Final
roll_trim_success	Number of successful trims in roll
roll_trim_failure	Number of failed trims in roll
pitch_trim_success	Number of successful trims in pitch
pitch_trim_failure	Number of failed trims in pitch
iPass_heading_criteria	Flag to indicate Pass/Fail of heading test
iPass_groundspeed_criteria	Flag to indicate Pass/Fail of groundspeed test
iPass_vsi_criteria	Flag to indicate Pass/Fail of vsi test
iPass_centerline_criteria	Flag to indicate Pass/Fail of centerline test
iPass_uav_bank_angle_test	Flag to indicate Pass/Fail of bank angle test
iPass_lateral_velocity_test	Flag to indicate Pass/Fail of lateral velocity test
iPass_pitch_test	Flag to indicate Pass/Fail of pitch test
iPass_altitude_criteria	Flag to indicate Pass/Fail of altitude test
iPass_glideslope_criteria	Flag to indicate Pass/Fail of glideslope test
iPass_groundtrack_criteria_approach	Flag to indicate Pass/Fail of groundtrack (approach) test

iPass_groundtrack_criteria_final	Flag to indicate Pass/Fail of groundtrack (final) test
iUser_abort	Flag to indicate if user selected to abort test
fResearch_wind_speed	Wind speed
fResearch_wind_direction	Wind direction

Reconnaissance Task Summary File

cbp->research_subject_number	Participant number
cbp->research_trial_number	Participant trial
cbp->research_session_number	Participant session
cbp->research_scenario_number	Participant scenario
etcbl_tx	Subjects cloud hole guess x coordinate
etcbl_tz	Subjects cloud hole guess z coordinate
fResearch_total_time_on_target	TOT with minor violations
cbp->research_time_on_target	TOT with no violations (no minor or major)
fResearch_cb_total_violation_time	Total violation (major) time
dCloud_hole_click_distance	Error for guess of cloud hole center
roll_trim_success	Number of successful trims in roll
roll_trim_failure	Number of failed trims in roll
pitch_trim_success	Number of successful trims in pitch
pitch_trim_failure	Number of failed trims in pitch
cbp->research_uav_elev	Start altitude
cbp->research_uav_head	Start heading
cbp->research_uav_speed	Start speed
cbp->research_hole_elev	Hole altitude
cbp->research_hole_radius	Hole radius
cbp->trial_duration_seconds	Trial duration in seconds
fResearch_wind_speed	Wind speed
fResearch_wind_direction	Wind direction
cb_camera_first_hits_target_start_time	When timing started for first hit counter (should be 0.00)
cb_camera_first_hits_target_delta_time	Time from start of trial until first hit
cb_on_target_time_count	Total number of on target events
cbp->research_stall_violation_count	Stall violation count
cbp->research_altitude_violation_count	Altitude violation count
cbp->research_roz_violation_count	ROZ violation count
cb_bank_angle_violation_count	Bank angle violation count
cb_operator_first_hits_violation_start_time	When timing started for first vio counter (should be 0.00)
cb_operator_first_hits_violation_delta_time	Time from start of trial until first violation
cb_speed_flag_time_count	Total count of speed violations
cb_alt_flag_time_count	Total count of altitude violations
cb_roz_flag_time_count	Total count of ROZ violations
cb_bank_angle_violation_count	Total count of bank angle violations
cb_caged_time_count	Total count of caged requests
cb_pan_time_count	Total count of pan requests
cb_gimbal_time_count	Total count of gimbal requests

APPENDIX C: DEMOGRAPHIC QUESTIONNAIRE AND CONSENT FORM

INFORMED CONSENT

"Predator UAV Flying Experience Study"

In this study you will be asked to participate in several different tasks extended over multiple days. Some of these tasks include becoming familiar with basic flight dynamics, becoming familiar with Predator Unmanned Aerial Vehicle displays and controls, flying standard maneuvers in a simulator, and flying Predator-specific tasks in a simulator. The goal of this study is to assess the type and amount of flying training necessary to operate the Predator Unmanned Aerial Vehicle.

There are no risks, physical discomforts, or expected emotional discomforts associated with participation in this study. Your participation is strictly voluntary; you are allowed to withdraw from the study at any time and for any reason. Furthermore, your performance data is kept strictly confidential. The data will be stored by a randomly assigned number and not by name. The data will then be pooled with data from other people of similar experience. We are interested in comparing performance amongst these pooled groups of data.

Our study is designed to evaluate the differences in performance between various groups of people. If other potential participants are informed of the purpose of the study, specifics of the tasks, or strategies employed during the study, biases may emerge in our data. Therefore, we urge you to avoid discussing details of this experiment with others. Please have those interested direct their questions to the experimenter.

Signature on this consent form acknowledges an understanding that participation is voluntary and is on a non-interference basis with Air Force duties.

Finally, we wish to thank you for your participation in this study!

Name (printed)____

Name (signed)____

Date________________________________

UAV OPERATOR STUDY BACKGROUND QUESTIONNAIRE

Date__________Group______________________________Participant #_________

Age____ Sex   M F

Do you wear corrective lenses? NO   GLASSES   CONTACTS

Highest education level attained:
_____ High School
_____ Some college, but no degree
_____ Two-year degree
_____ Four-year degree or higher

If you are in the military:

Grade:	__________
Air Force Specialty Code	__________
Time in Present Job	_____yrs _____mos
Total Active Federal Military Duty	_____yrs _____mos
Time in Career Field	_____yrs _____mos

Pilot Experience

What military pilot training have you had? (please check all that apply)
_____ None
_____ Glider
_____ Ground school
_____ T-3
_____ T-37
_____ T-38
_____ T-1
_____ Initial qualification in an operational aircraft
_____ Mission qualification in an operational aircraft
_____ Other (please specify ________________________________)

What private pilot training have you had? (please check all that apply)
_____ None
_____ Enrolled in ground school now
_____ Ground school for private pilot's certificate
_____ Private pilot's certificate
_____ Instrument rating
_____ Commercial pilot certificate
_____ Airline transport pilot certificate
_____ Other (please specify ________________________________)

Please list the number of hours you have flown particular **airplanes, gliders, other airborne craft,** or **military or commercial flight simulators**?

__________________ #hrs __________ __________________ #hrs __________

__________________ #hrs __________ __________________ #hrs __________

__________________ #hrs __________ __________________ #hrs __________

__________________ #hrs __________ __________________ #hrs __________

__________________ #hrs __________ __________________ #hrs __________

__________________ #hrs __________ __________________ #hrs __________

What is the most recent aircraft you have flown, and when was the last time you flew it?

____

Date last flown _______________________

What is the most recent simulator you have flown, and when was the last time you flew it?

____

Date last flown_______________________

Miscellaneous Interests

On average, during the last six months, how many hours per week did you typically spend playing flight simulation video games?___________ (enter 0 if you did not use flight simulation games)

Please check the amount of lifetime experience you have playing flight simulation games.
_____ None
_____ 1-10 hours
_____ 11-50 hours
_____ 50-200 hours
_____ Over 200 hours

On average, during the last six months, how many hours per week did you typically spend playing 3-D action, sports, or driving video games (such as Doom, Quake, Tomb Raider, Madden NFL, F1 Racing Simulation—not flight simulation games)?___________ (enter 0 if you did not play 3-D action, sports, or driving games)

Please check the amount of lifetime experience you have playing 3-D action/sports/driving games.
______ None
______ 1-10 hours
______ 11-50 hours
______ 50-200 hours
______ Over 200 hours

On average, during the last six months, how many hours per week did you typically spend operating model remote control vehicles (model airplanes, boats, cars, etc.)?____________(enter 0 if you did not operate remote control vehicles)

Please check the amount of lifetime experience you have operating remote control vehicles.
______ None
______ 1-10 hours
______ 11-50 hours
______ 50-200 hours
______ Over 200 hours

Please feel free to write any comments you may have about the study.